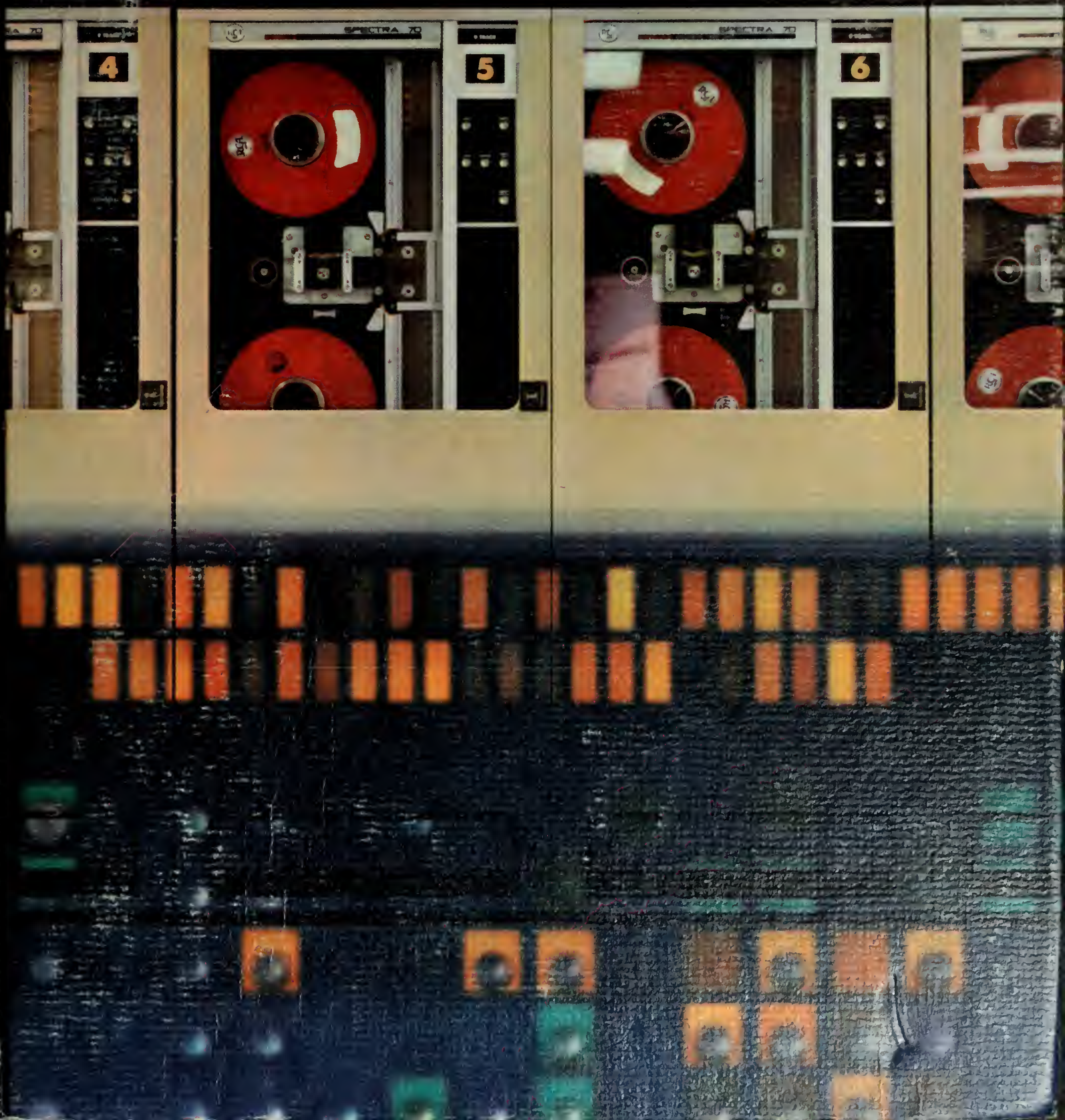
A GUIDE TO SCIENCE

AND INDEX TO THE LIFE SCIENCE LIBRARY



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A GUIDE TO SCIENCE

and Index to the LIFE Science Library

by the Editors of **TIME-LIFE BOOKS**

TIME-LIFE BOOKS NEW YORK

EDITOR'S NOTE:

THIS VOLUME, *A Guide to Science*, completes the introduction to the world of science and its applications in society that makes up the LIFE Science Library. It has been a large task, calling on the talents of more than 100 scientists—including several Nobel Prize winners. Its previous 25 books, containing more than a million words and 5,000 illustrations, have been translated into as many as 14 languages.

More important than the size of the LIFE Science Library, or the effort that went into it, has been its direction. These books take a new approach to the popularization of science. Emphasizing the unity that underlies modern understanding of the universe, each volume examines many facets of a significant topic rather than one academic discipline. Every volume cuts across traditional divisions; *Water* discusses physics, chemistry and sociology, among other sciences, as they bear on the title subject; biology is an integral part of *Planets*.

A Guide to Science follows a different plan from that followed in the earlier books. It includes an index covering the entire LIFE Science Library, a survey of the history of science and eight picture essays describing individual fields. The first essay deals with the smallest known objects, the subnuclear particles of the atom; successive essays take up objects of increasing size, such as animals and human beings, and conclude with the largest known objects, stars and galaxies. As these separate fields are explained in text, photographs and drawings, their interrelationships become clear, for all fit into one progressive line of development and all obey the same universal laws of nature.

—MARTIN MANN
Editor, LIFE Science Library

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ON THE COVER

Magnetic-tape decks store data in a computer—one of the swift calculators used in modern science for such disparate tasks as plotting spacecraft courses and diagnosing human ailments. The abstract design on the back cover, depicting an electron circling an atomic nucleus or a planet orbiting a star, symbolizes a basic pattern of science.

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Published simultaneously in Canada. Library of Congress catalogue card number 67-29962.
School and library distribution by Silver Burdett Company, Morristown, New Jersey.

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The Soaring Curve of Science

Viewed from a spacecraft, the earth appears over the rim of the moon *(foreground)* as it might to a scientist floating in space—a medium-sized planet that he knows as land and water, rich in life, composed of submicroscopic particles.

SCIENCE is the great adventure of the human race. Through science, man has already learned to dominate the earth, defeat all enemies and competitors, construct muscles and brains more powerful than his own. Its exploits still continue, coming at closer and closer intervals. Each generation sees more change, and the curve of change sweeps upward at an ever-steepening pitch. Where it will take mankind cannot be foreseen—perhaps to disaster, perhaps to the stars.

Nothing like the present explosion of science and science-based technology, beginning in the 16th Century, ever happened before in all of human history. Earlier civilizations in Mesopotamia, Egypt, China and Greece reached high levels of sophistication, but none of them adopted the scientific methods that have given modern Western culture its runaway success. The failure of the ancients is hard to account for, but it seems to have set an upper limit to their development. With monotonous regularity they climbed to a climax and sank into decadence. None of them reached that critical point, the threshold of a limitless future, that the West passed 400 years ago.

The ancient Greeks came nearest to breaking out of the cycle of repeated rise and fall. Toward the end of their period of greatness, just before the Christian Era, a few of their philosophers started to use the combination of clear-eyed observation and theoretical reasoning that is the essence of scientific research. Some of their work sounds wholly modern. Eratosthenes, born about 273 B.C., estimated the earth's circumference with surprising accuracy by a method (measurement of sun shadows at different localities) that remains valid today. Greek physicians dissected human bodies to find out how they work, an obviously necessary practice that was discouraged in later centuries. The mathematician Archimedes used his famous Archimedes' Principle (that the weight of a body immersed in a fluid diminishes by an amount equal to the weight of the fluid displaced) to measure the density of irregular objects. This is an excellent example of scientific theory put to practical use. When his native city, Syracuse, was attacked by the Romans in 212 B.C., he turned, like a modern scientist, to what is now called military research and development, and designed improved catapults and other new weapons.

During Archimedes' time, science of the late Greek period seemed to be gaining momentum. Several cities had large public libraries, and the famous Museum at Alexandria, a Greek colony in Egypt, was partly an institute of scientific research. Theoretical knowledge was increasing along with practical technology, and each was stimulating the other in the modern manner. The Greeks of the Second Century B.C. were entitled to feel that they lived in a wonderful age of discovery, when nature was yielding on every side to the power of the human intellect.

If this spirit had been maintained, the present era of explosive change, which began about 1600 A.D., might have begun 1,700 years earlier, and perhaps the earth's first colony on the moon would have spoken Greek. But the Greeks' late spurt of scientific progress was short-lived. Soon after 100 B.C. the Greek world lost its vitality and was conquered by the

practical Romans, who were excellent engineers but did little original scientific thinking. Then came Christianity, emphasizing mysticism, not science. Even before barbarian invaders brought the so-called Dark Ages to Europe, its scientific thought had ceased. The Greco-Roman civilization, like all its predecessors, had hit its ceiling and turned downward.

After a thousand years of ignorance and superstition European science began a slow recovery. In the 13th Century a few daring men like Roger Bacon, a Franciscan friar at Oxford University, rejected theological habits of thought and began to observe and reason as the best of the Greeks had done. Bacon studied lenses and may have used an effective microscope. Most important of all was his radical philosophical attitude. He urged his disciples to experiment and observe and to accept only what came from nature. This sort of thinking is the key to scientific and technical accomplishment, and with amazing vision Bacon predicted that it would enable men to construct self-propelled boats and land vehicles. He even foresaw ships that would dive under the oceans and fly through the air.

Bacon was centuries ahead of his time. He was imprisoned and silenced by the ecclesiastical authorities, who considered his independent reasoning a threat to religious orthodoxy.

Science and sorcery

After flourishing briefly in the 13th Century, science went underground in medieval Europe, but it did not die, because Europe was then on a technological upgrade. Already secret laboratories had been established by the alchemists, who were part sorcerers, part chemists. Their principal objective was to make gold out of base metals. Although this transformation is now known to be impossible by chemical means, the alchemists learned a lot about chemistry as they pursued their goal. At the official universities scientific thought was never wholly absent, but since the universities were run by the Church, reasoning about nature was sometimes protectively colored by mixture with theology. Scholars discussed the motions of the planets and debated whether they moved by themselves or whether God had to keep pushing them around the sky. Pretending—or really believing—that they were discussing the customs of God, the scholars were actually reasoning about the basic laws of motion.

Practical technology, too, was progressing, but the medieval craftsmen who made clocks, firearms, navigation instruments and other new devices were often illiterate. Their knowledge was passed from man to man by word of mouth and was often kept secret by their tightly organized guilds. Although these imaginative mechanics were the equivalent of modern engineers, they had little contact with scholars, and they were not yet able to help theoretical science or to be helped by it.

Not until the 16th Century did the revolution of thought begin. Modern science is generally considered to have started with astronomers who questioned the ancient belief that the sun, the planets and the stars revolve around the earth. Their struggle to establish the sun-centered view

of the solar system caused a famous stir in intellectual circles, but it probably had less effect on the takeoff of science than the gradual weakening of the long-established barrier between craftsmen and scholars. By the 16th Century a few men who knew about trades such as gunpowder-making or mining began to write, and the young art of printing spread their knowledge to all literate persons who were interested.

A dipping needle, magnetized filings

One of these technicians was a London compass-maker named Robert Norman, who published in 1581 a pamphlet, "The Newe Attractive," describing his experiments in magnetism. He suspended a magnetic compass needle freely by its center and found that while one end pointed toward the north, it also dipped downward as if pointing at something below the earth's surface. He also carefully weighed iron filings before and after magnetizing them, and when he found no difference, he decided—correctly—that magnetism has no weight. Such experiments are conducted on a grade-school level now, but they are modern in spirit, and in the 16th Century they were wonderfully fresh and daring.

A hundred years earlier Norman's humble tinkerings with iron filings and compass needles would not have attracted the attention of haughty scholars, but now a new curiosity about the mysterious ways of nature was stirring in the minds of educated men. A few years after the appearance of Norman's pamphlet, William Gilbert, who was Queen Elizabeth's court physician, extended Norman's work in a more theoretical way. He made spheres of lodestone (magnetic iron ore), which he called "little earths." Pretending that they were the real earth, he traced the magnetic forces on their surfaces by moving a tiny compass around them as if it were on a ship sailing the earth's oceans. The motions of the needle showed that each little earth had north and south poles, and when the needle pointed toward one of them it also dipped downward as Norman's needle had done. Gilbert's conclusion—that the earth is a giant sphere of lodestone—was wrong, but his method of working was thoroughly right. He dedicated his treatise on magnetism to "men who look for knowledge, not in books, but in things themselves."

Gilbert was not alone. In many countries of 16th Century Europe scholars were discovering that fresh and valuable knowledge could be found "in things themselves." They were questioning, doubting, rejecting traditional authorities, observing nature with their own eyes and thinking about their observations with their own brains. Some scholars allied themselves with craftsmen and tried to derive theoretical laws from the knowledge of these practical men. Such collaboration seems natural and normal to modern people who live in a world that is dominated by scientists working closely with engineers, but it was almost unknown before the scientific revolution.

There is nothing mysterious about the method by which scientists increase human knowledge of nature. The scientist's starting point is nature itself. He begins with an observation or set of observations that may

be about almost anything: the behavior of steam in an engine, the light that comes from a star or even a phenomenon as evanescent as human dreams. The observation need not be new; it may be old but unexplained, and the scientist may have made it himself or heard it from someone else. In any case, his first step is to make sure that the observation is real and not an error or illusion. He may do this by repeated experiments in his laboratory, or by searching for identical observations in the published reports of other scientists.

From a theory to a law

Even while this preliminary testing process is incomplete, the scientist is likely to get gloriously excited. His imagination races ahead; he thinks of dozens of ways by which the observation may lead to a new law of nature—a general rule explaining the connections between many different observations. His early speculations often prove wrong; they may be knocked down by conflicting facts or tighter reasoning, but if the scientist persists and is lucky, he eventually finds a hypothesis, a tentative theory, that seems to explain the observed facts in which he is interested.

Greatly encouraged now and perhaps a bit smug, he sets up an experiment whose outcome he will be able to predict if the hypothesis is valid. Anxiously he watches a pressure gauge, an oscilloscope or some other instrument. Readings that fall within a certain range will show that his hypothesis has stood the test. If it does, he rejoices, writes a report about it and wins the approbation of his colleagues. If it does not, he looks for flaws in his reasoning or apparatus, or perhaps starts all over again. After the hypothesis has passed many tests it becomes a dependable theory, and other scientists use it to lead them to still newer knowledge. Only if it survives for many years and proves of wide importance is it promoted to the rank of a law. Then it becomes part of the framework of the natural world, to be used in hundreds of ways by technicians.

In modern times important new laws of nature are becoming increasingly hard to discover and must be sought with elaborate apparatus and abstruse mathematical reasoning. But in the 16th and 17th Centuries the laws lay close to the surface, waiting for men of audacity and vision to find them. The work on gases done by Robert Boyle (1627-1691) is a good example of such a search. Boyle lived at a time when all that anyone knew about gas pressures was that "nature abhors a vacuum." He called on the best craftsmen to build improved air pumps and other apparatus with which to measure how much air was left in a tight container after the pump had been evacuating it for a while. In the course of this work he began to get hints of a simple relationship between the volume occupied by a given quantity of air and its pressure. It looked as if the volume were inversely proportionate to the pressure.

To test this speculation Boyle ran a series of experiments. He doubled the pressure of an air sample and found that its volume was cut in half. When he let the air expand to twice its original volume, it lost half its pressure. Intermediate pressures gave intermediate volumes, and air

behaved in an identical way when it was put through its paces in different apparatus. Boyle found no significant exceptions. His speculation became a hypothesis, then a theory and finally a law of nature. Boyle's Law (it states that at constant temperature the volume of gas varies inversely with the pressure) is the foundation of a large part of physics and chemistry, and is used in countless theoretical and practical ways. It is a classic example of a law that was derived from a simple experiment but proved to have great consequences.

Boyle's Law is so easy to demonstrate that it seems remarkable that the Greeks did not discover it. Their technology was good enough to build the apparatus that Boyle used, and some of them experimented with gases under pressure. But even if the Greeks had discovered Boyle's Law, the chances are that they would not have used it to extend their understanding of nature as the Western Europeans did. Their society was not ready for a broad advance. Over half of the people were slaves or serfs. Printing had not been invented; books were rare and expensive, and literacy was limited.

Western Europe in Boyle's time had a wholly different kind of society. It was boiling with enterprise, disdainful of the past, hopeful for the future. Its population was increasing; its seamen, explorers, colonists and empire builders were spreading over the earth armed with improved weapons that few non-Europeans could resist. The new ideas and products that they brought home in turn greatly stimulated European technology and thought. Literacy was becoming common, especially in Protestant countries where Bible reading was an important part of religious life. In a momentous break with tradition, even the children of some workingmen were beginning to go to school, and university educations were no longer limited to churchmen and aristocrats.

An intellectual "critical mass"

Like the minimum mass of uranium 235 that is required to sustain nuclear fission, Western Europe had become an intellectual "critical mass," and through it swept the flame of science like a chain reaction. Each step of scientific growth increased the factors that encouraged faster growth.

When science was beginning to develop in the 16th Century, the richest hunting ground for scientific data was the accumulated knowledge of practical men who did not think of themselves as scientists. The scholars had little to do with these craftsmen and early engineers, who though often ignorant of mathematics, or even illiterate, knew a great deal about building large bridges, fermenting beer, or arranging the sails of a ship to get the most propulsion out of the wind. Designers of machines seldom drew a plan on paper and were never more than dimly aware of the formal laws of mechanics. Pure science used these technicians and their knowledge; it could not have advanced without them.

Scientific instruments were prime examples of applied science; in current jargon these are "hardware" and are sometimes looked down upon

by the theoreticians. Some of them, nevertheless, practically created new sciences. Before the development of an effective microscope in the 17th Century, botany and zoology were dull affairs that had not advanced very much since Greek times. They were still largely a matter of collecting plants and animals and classifying them by means of their superficial appearance. Then came the microscope, which showed undreamed-of detail in every organism and revealed that every film of water, every particle of soil, teems with tiny, invisible creatures, just as alive as their human observer. These wonders, which transformed man's ideas about the living world, were discovered by means of a few small bits of artfully curved glass. Thanks to the microscope, botany and zoology became lively sciences with inexhaustible mysteries to explore.

In the 18th Century technology added more fuel to the chain reaction of science by furthering industrialism. Until that time nearly all work was done by human hands and muscles, and most of the population consisted of unlettered and inarticulate peasants who consumed almost all the food they grew, leaving little surplus for nonfarmers. Cities were generally small, and even the largest of them had only a few people who did not earn their living in simple manual ways.

In such a society, skilled and specialized craftsmen could not be numerous, and scientists of any kind were extremely rare. There was little support for them. The few universities concentrated almost exclusively on the humanities, so that only an occasional scientist could make a living by teaching in one of them. Some of the alchemists were subsidized by kings who hoped they would succeed in making gold and therewith fatten the royal treasury, and a few astronomers got on government payrolls because of the prevailing belief that they could predict the future by watching the motions of the planets. These were fortunate exceptions. Most scientists had to be supported by inherited wealth or risk debtors' prison. Galileo Galilei, who founded the modern theory of mechanics, came from a well-to-do Florentine family; Robert Boyle was a son of the Earl of Cork.

The new class of scientists

The beginnings of industrialism in the 18th Century changed all this. In the growing towns there appeared a numerous class of highly skilled craftsmen, engineers and managers whose prosperity supported physicians, lawyers and other educated people. Schools at all levels up to the universities were vastly expanded to train such men, and scholars with talent for pure science found employment in them. As soon as the Industrial Revolution was well under way, scientists no longer had to be sons of earls. Scientists became more numerous, and so did their discoveries. Industrialism was an effect of technology and applied science, but by supporting more scientists it was also a powerful stimulus for pure scientific research.

As science grew and became more complicated it separated into departments, and subdepartments. There may have been a time, perhaps

in the 17th Century, when all of man's formal science could have been crammed into one human brain, but the scientific revolution soon swept past this point. Rapid increase of knowledge compelled specialization. As it grew, science branched like a seedling tree that starts as a single shoot, then forks and forks again.

It was not quite so simple as that, of course. Different kinds of science took shape at different times and in different ways. Medicine, which began with ancient shamans and witch doctors, is usually honored as the father of biology, but ancient plant and animal breeders must have contributed much of the knowledge of nature that grew into biology.

The sciences' family tree

Charts can be drawn showing the history of how the scientific specialties that are recognized today grew out of generalized ancestral sciences. It is clear, for instance, that aerodynamics grew out of physics, and ornithology (the study of birds) is obviously a branch of zoology. But some sciences are hardly more than convenient names. Oceanography, for instance, can be called a science, but it is really a field of interest for many kinds of scientists. When an oceanographic research ship sets out on a long voyage, it takes a mixed scientific crew to study the living creatures in ocean water, the water itself, the ocean bottom, the earth's crust under the oceans and the atmosphere above them. These men are all oceanographers, but they are also meteorologists, geophysicists and biologists.

There is no limit to the number of twiglets into which science can branch. Men who specialize in eggs sometimes call themselves ovologists, and students of the flow of matter are rheologists. Some of these specialties are forgotten when interest in them fades; others grow into major fields of research. Genetics, the study of heredity, was a minor specialty of biology until a generation ago, when new techniques and discoveries made it freshly exciting and attracted swarms of students.

Separate sciences sometimes merge like branching roots that meet underground and graft together. Biology was once considered wholly separate from chemistry, but when 19th Century chemists discovered that they could synthesize many compounds produced by living organisms, the two sciences hybridized. Biochemistry is now an important part of both chemistry and biology and is credited with the most important recent advances in the understanding of life. Biophysics is another hybrid formed in this way.

Since sciences branch and hybridize, there is no clear way to classify them. Perhaps as practical a compromise as any is to arrange them in arbitrary groups according to the size and nature of the objects that they study:

Physics, first of the arbitrary groups of sciences, deals with the smallest objects: the subatomic particles—protons, electrons, photons, etc. —out of which matter and energy are formed. But it is also concerned with the behavior of atoms and energy in large quantities.

Chemistry studies atoms hitched together to form molecules. Nearly everything on earth is made of molecules, and chemistry is minutely subdivided. It is also so important economically that chemists make up the most numerous group of scientists by far.

Biology treats the huge molecules that form living things—viruses, bacteria, protozoa and larger organisms.

Earth science occupies many different specialists in the examination of our planet. Meteorologists specialize in the atmosphere, and try to use their fast-growing knowledge to forecast or even control the weather; geophysicists, geochemists and geologists study the earth as a whole and the details of its crust.

Astronomy focuses on the largest of all objects: the universe. Beyond the moon and planets lie the stars of the Milky Way, and beyond them are the external galaxies, more than a billion of them, that form the known universe. Man's knowledge of the universe is continually extending, but the ultimate questions—how big is the universe, how was it formed and what will happen to it—are still wrapped in mystery.

Comprehensive as they are, these five groups do not exhaust the full range of modern science. For one thing, mathematics does not fit into any of these categories; it is essentially a language that all scientists use in increasingly complex ways to describe and understand nature. For another, the five groups omit certain significant subdivisions of the sciences, and all of the vast area in which science is directly applied to the service of man.

Anatomy, for example, is a subdivision of biology that is concerned exclusively with the structure and function of whole organisms.

Psychology and medicine, which overlap biology on the one hand and applied science on the other, deal with the special characteristics of one large organism, Homo sapiens, or modern man.

Technology, the field of applied science as a whole, includes all the practical fruits of science, from toothpaste and radios to spaceships and giant dams.

From atoms to stars

The eight picture essays in this book cover all the fields listed above, in an order that progresses from the smallest objects of scientific study to the largest. Thus, the first three essays deal in sequence with the atomic particles studied in physics, with the molecules of chemistry, and with microscopic living organisms. Essay Four deals with larger organisms in terms of comparative anatomy, Essay Five with man in terms of psychology and medicine. The last three picture stories are devoted to pure and applied sciences that deal with still-higher orders of magnitude: technology, which includes the largest objects man has made; earth science, which studies the globe on which he lives; and astronomy, which extends to the limits of the known universe.

All the sciences are progressing rapidly, but the most extraordinary thing about the modern age of science is that its *rate* of progress is

continuing to increase. During each generation since the early years of the scientific revolution men have marveled about the changes that took place during their lifetimes, and many predicted that the rate of change must soon decrease. Nothing of the sort happened. Generation after generation, the sciences have increased their rates of advance, and technological changes in the human way of life have come faster and faster.

The destination of a soaring curve

Philosophical scientists, and nonscientists too, sometimes wonder where the explosive sweep of modern science will end. It now seems to be climbing without limit, each branch helping the others. The electron microscope, which was developed by applied physics, has been an enormous stimulus to all other sciences and to practical technologies such as medicine and engineering. Delicate methods of chemical analysis have helped physics by making small traces of matter detectable. Industrial technology has helped by making machines do the work of human muscles and hands and thereby freeing more brains for scientific thinking. And today more freedom for creative thinking is coming from computing machines, one of which may do the routine figure work that once required thousands of human brains.

Pushed by all these interactions and with no repressing factor at work, science is rising on an exponential curve like the curve of the powers of two: 2...4...8...16...32...64, etc. Each stage of scientific progress is not only higher than its predecessor but differs from it by a greater amount.

It has been said that 80 to 90 per cent of all scientists who ever lived are alive today. This is not quite as extraordinary as it sounds; it is merely a way of saying that the number of scientists has been doubling every 15 years during the last three centuries. The earth's general population, thanks mainly to science, is increasing almost as fast, but scientists have an impact on civilization that most other people do not: their discoveries are cumulative. The facts, rules and laws that they wrest from nature are stored in libraries where they can be used to increase the rate of future discovery. So man's stock of scientific knowledge and his power over nature are increasing even faster than the number of scientists.

Where will the climb of science end? Exponential curves cannot continue to rise indefinitely. Science may fetch up against natural barriers that the human intellect and its artificial allies, such as computers, cannot break through. Or perhaps a new Dark Age will begin, with antiscientific mobs destroying laboratories as they did in Alexandria just before the fall of the Roman Empire. Conceivably the uncontrolled forces released by science could destroy mankind. But it is also possible that science may turn its attention to making the earth more pleasant for man instead of more crowded and dangerous. There is no absolute reason why man's greatest adventure should not have a happy ending.

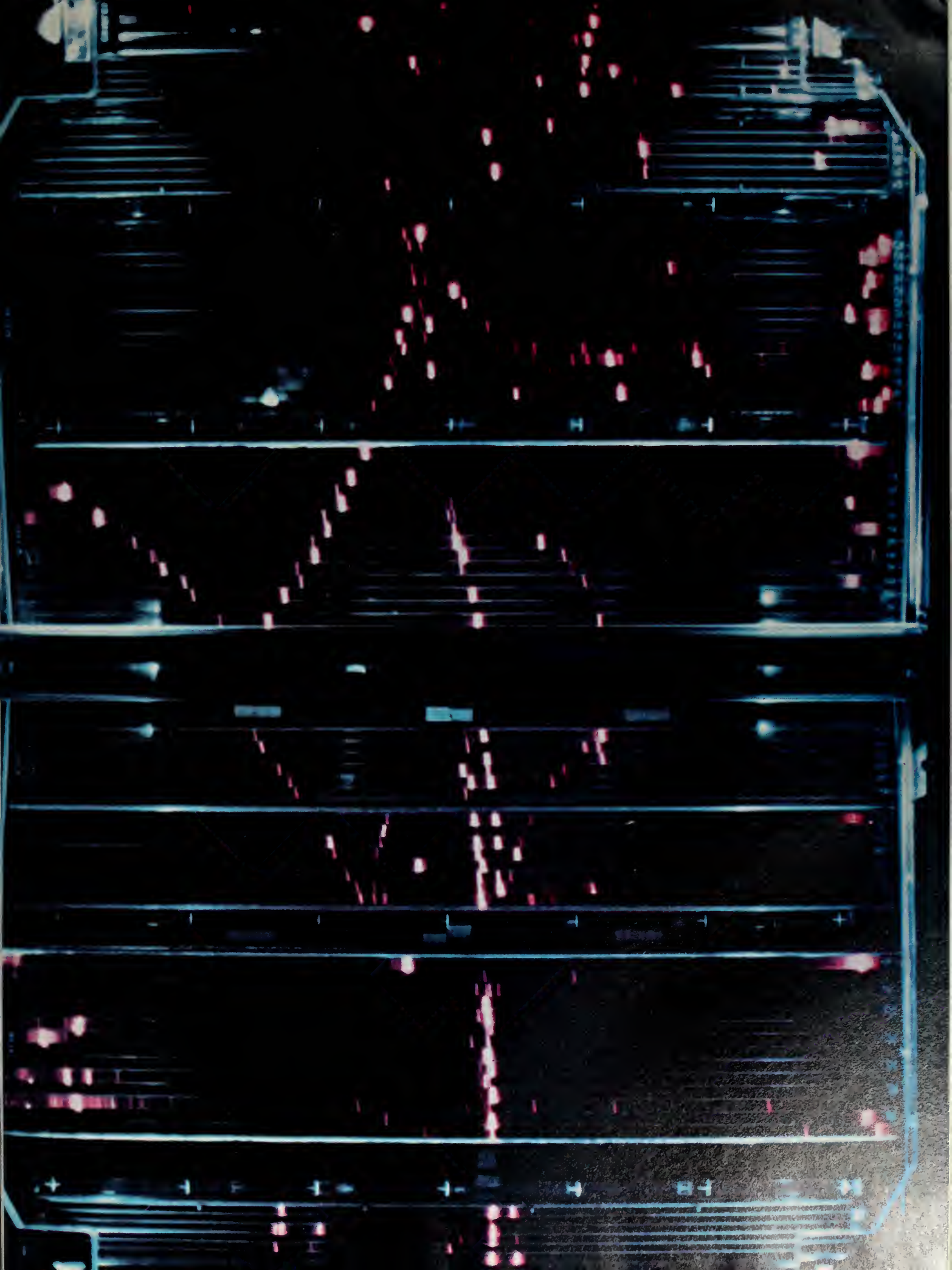
Physics: What the World Is Made Of

Man is an explorer, and science has led him on the greatest exploration ever undertaken, aimed at nothing less than an understanding of the whole universe. Science combines the power of the human senses with that of the human intellect, leading both powers far beyond their old limits. The alliance has revealed a universe extending over distances of billions of trillions of miles—and yet everywhere made of the same unimaginably tiny pieces.

Until the 1890s, the smallest known things in the universe were atoms, which in 92 basic types form the 92 elements making up all ordinary materials. But the atoms turned out to be relatively gigantic. With complex instruments, physicists have discovered that atoms can be broken apart *(right)* into a bewildering collection of lesser particles, each measuring less than a trillionth of an inch across. In their span of existence as well as their size, these particles strain man's concept of the infinitesimal: some of them endure for only a few trillionths of a trillionth of a second. Even as this evanescent microworld is beginning to come clear, some physicists speculate that the smallest of the small has not yet been reached—and wonder if a limit to smallness indeed exists.

TRACING THE PATHS OF PARTICLES

The instrument at the right, called a spark chamber, illuminates some of the universe's smallest fragments by streaks of electricity. The chamber contains a series of electrically charged metal plates that are surrounded by gas. When tiny, invisible particles pass through the chamber, electricity flashes between the plates, following the paths of the particles.

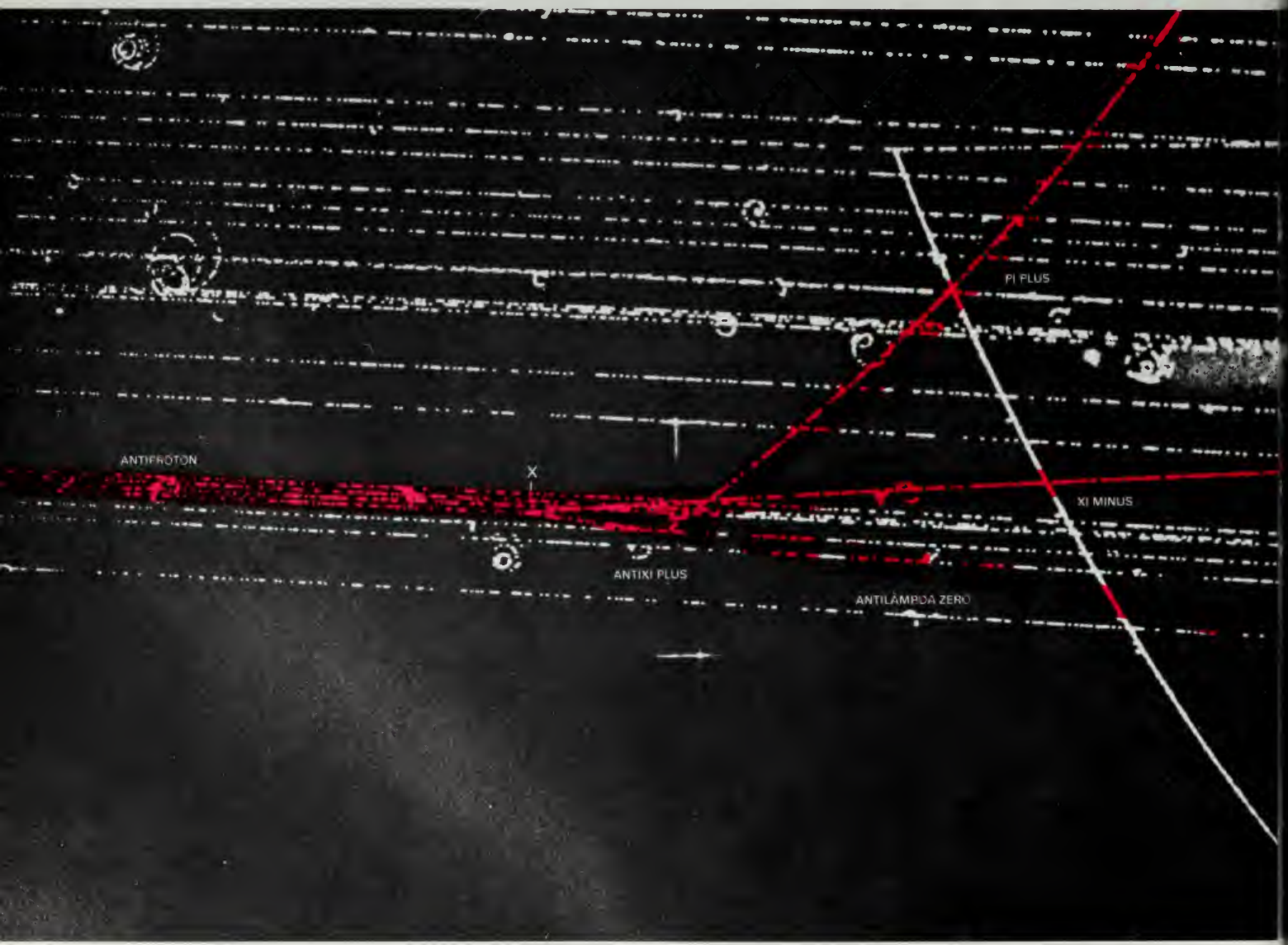


The Tracks of Atomic Debris

Like any good hunter, the physicist can learn a great deal about his quarry—the smallest known particles in the universe—by careful study of their tracks *(below)*. He must rely on such indirect observations, for the particles are too small and too fleeting ever to be seen. Ironically, these particles are created by the biggest instruments used by science—machines that accelerate bits of matter almost to the speed of light and send them smashing into atoms. The collisions produce a host of new elementary particles. By linking a spark chamber or a bubble chamber to these machines, scientists can observe the tracks of new particles leaving the shattered atoms.

Physicists wryly call these varied particles a "zoo" because of the peculiar traits they display. The particles (a limited list is given at right) may be electrically positive, negative or neutral; they act sometimes like insubstantial waves and sometimes like solid bullets; they change from energy to matter and back; they decay almost instantaneously into new particles. For each of the particles normally found in nature, a mirror-image "antiparticle" with opposite charge and matter can be created by high-energy collisions.

The strangest characteristics of the world of subatomic particles are their number and variety. New ones are constantly being found, and how they can all fit into the grand scheme of the universe remains a mystery.



PARTICLE NAME	PARTICLE SYMBOL AND ELECTRICAL CHARGE	MASS COMPARED TO PROTON	AVERAGE LIFETIME (SECONDS)	ANTIPARTICLE SYMBOL AND ELECTRICAL CHARGE	ANTIPARTICLE NAME
OMEGA MINUS	Ω^-	1.787	00000000015	$\bar{\Omega}^+$	ANTIOMEGA PLUS
XI MINUS	Ξ^-	1.409	.000000000174	$\bar{\Xi}^+$	ANTIXI PLUS
XI ZERO	Ξ^0	1.401	.0000000003	$\bar{\Xi}^0$	ANTIXI ZERO
SIGMA MINUS	Σ^-	1.277	0000000001 65	$\bar{\Sigma}^+$	ANTISIGMA PLUS
SIGMA ZERO	Σ^0	1.272	00000000000001 OR LESS	$\bar{\Sigma}^0$	ANTISIGMA ZERO
SIGMA PLUS	Σ^+	1.267	0000000000081	$\bar{\Sigma}^-$	ANTISIGMA MINUS
LAMBDA ZERO	Λ^0	1.190	0000000002 51	$\bar{\Lambda}^0$	ANTILAMBDA ZERO
NEUTRON	n^0	1.002	1010.	$\bar{n}^0$	ANTINEUTRON
PROTON	p^+	1 000	DOES NOT DECAY	$\bar{p}^-$	ANTIPROTON
ETA ZERD	η^0	.585	00000000000000000001	η^0	ETA ZERO
K ZERO	K^0	532	0000000000087 (short type) 0000000586 (long type)	$\bar{K}^0$	ANTI-K ZERO
K PLUS	K^+	526	.0000000124	K^-	K MINUS
PI PLUS	π^+	.149	.0000000261	π^-	PI MINUS
PI ZERO	π^0	144	000000000000000089	π^0	PI ZERD
MU MINUS	μ^-	113	0000022	μ^+	MU PLUS
ELECTRON	e^-	00054	DOES NOT DECAY	e^+	POSITRON
NEUTRINO (MUON TYPE)	ν_μ	000	DOES NOT DECAY	$\bar{\nu}_\mu$	ANTINEUTRINO (MUON TYPE)
NEUTRINO (ELECTRON TYPE)	ν_e	000	DOES NOT DECAY	$\bar{\nu}_e$	ANTINEUTRIND (ELECTRON TYPE)
PHOTON	γ	000	DOES NOT DECAY	γ	PHOTON
GRAVITON	PREDICTED THEORETICALLY BUT NOT DETECTED				GRAVITON

PARTICLES AND THEIR TRAITS

The table at left offers a partial guide to the scientist's "zoo" of elementary particles, which are usually denoted by Greek letters. Three major distinguishing traits—electric charge, mass and average lifetime—are shown for each elementary particle and its antiparticle.

DISCOVERY OF A RARE PARTICLE

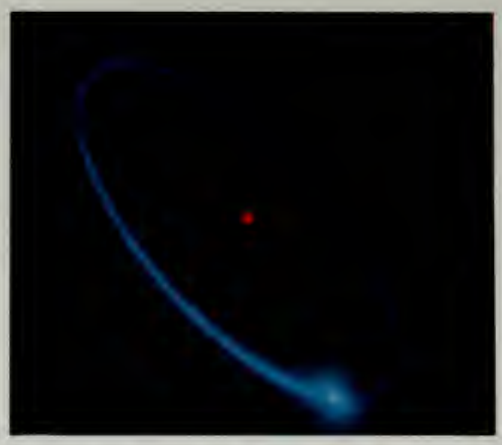
A rare antixi plus particle was first glimpsed in this 1962 photograph of a bubble chamber in action. The chamber is filled with liquid hydrogen, which hovers at the boiling point. When particles pass through the chamber, they cause bubbles to form along their paths. The red overlay shows how an antiproton entered from the left and collided with a proton at point X. This collision created an antixi plus particle—which survived for only .03 billionths of a second—and a xi minus particle. They changed into other charged particles *(solid lines)* and uncharged particles that leave no tracks. The spirals *(one shown in blue)* are tracks of electrons ripped from hydrogen atoms by the particles.

The Construction of Elements

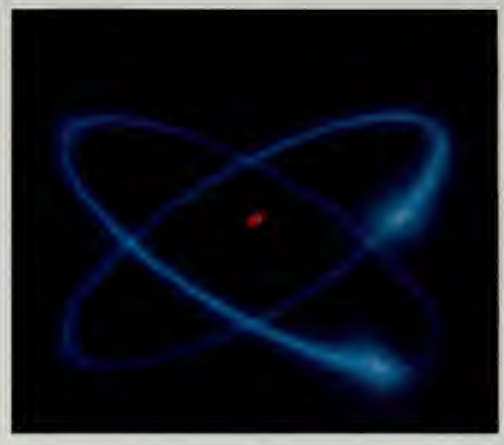
Most of the elementary particles in the physicist's "zoo" exist for only tiny fractions of a second after their creation. This is not the case, however, with such key particles as electrons, protons and neutrons. They have staying power and join together in varying combinations to make up the distinctive atoms of the chemical elements, such as iron and oxygen.

Atoms have a massive core or nucleus of protons and neutrons, surrounded by lightweight electrons, one for each proton. Although every atom is unimaginably small, it consists largely of empty space: if the nucleus were enlarged to a diameter of four inches, its companion electrons would be one third of a mile away.

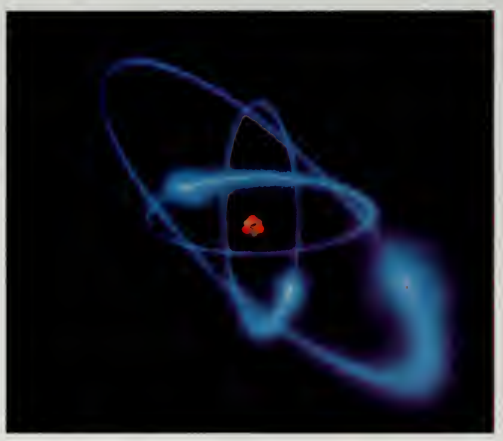
Atoms differ from one another according to the kind and number of parts that they contain. The simplest atom is hydrogen *(top, right)*, with its single proton and electron. The addition of more parts *(right)* produces progressively heavier mass, as well as distinctive changes in physical and chemical properties. Nature draws the line for size, in ordinary atoms, at 238 nuclear particles. In fact, the bulging nucleus of the atom with 238 parts—uranium 238 *(opposite)*—is notoriously rickety. Some elementary particles easily escape from the nucleus, splitting the atom and releasing gigantic bursts of energy—the energy of the atomic bomb.



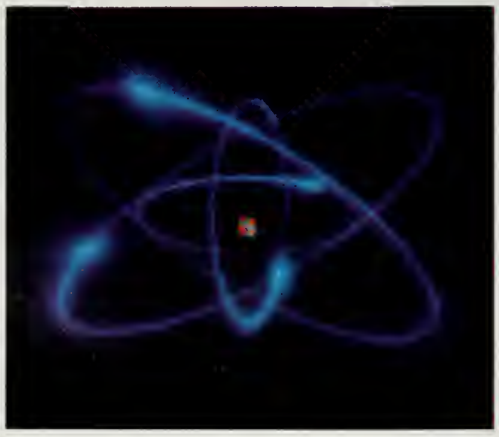
HYDROGEN



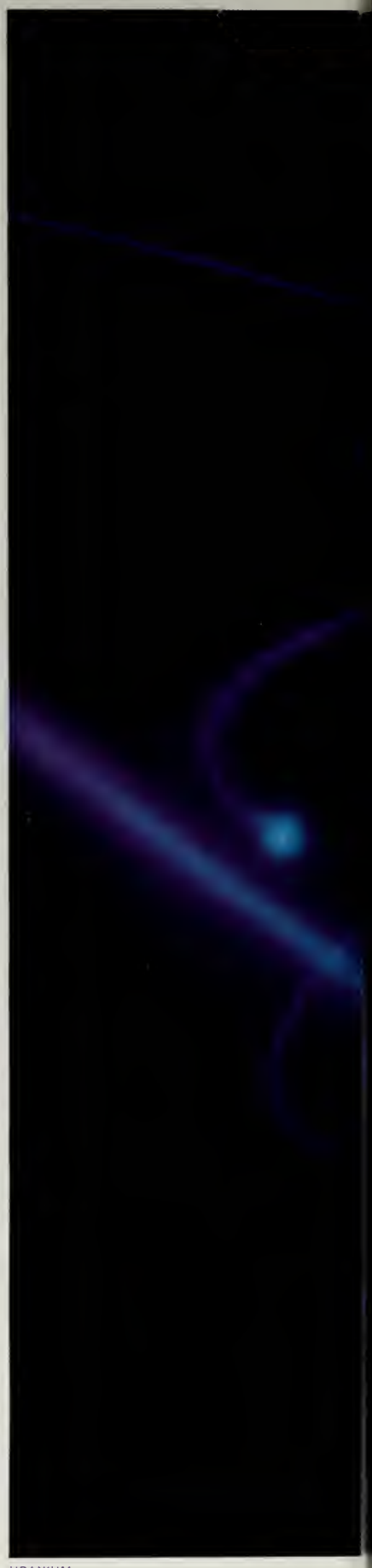
HELIUM



LITHIUM



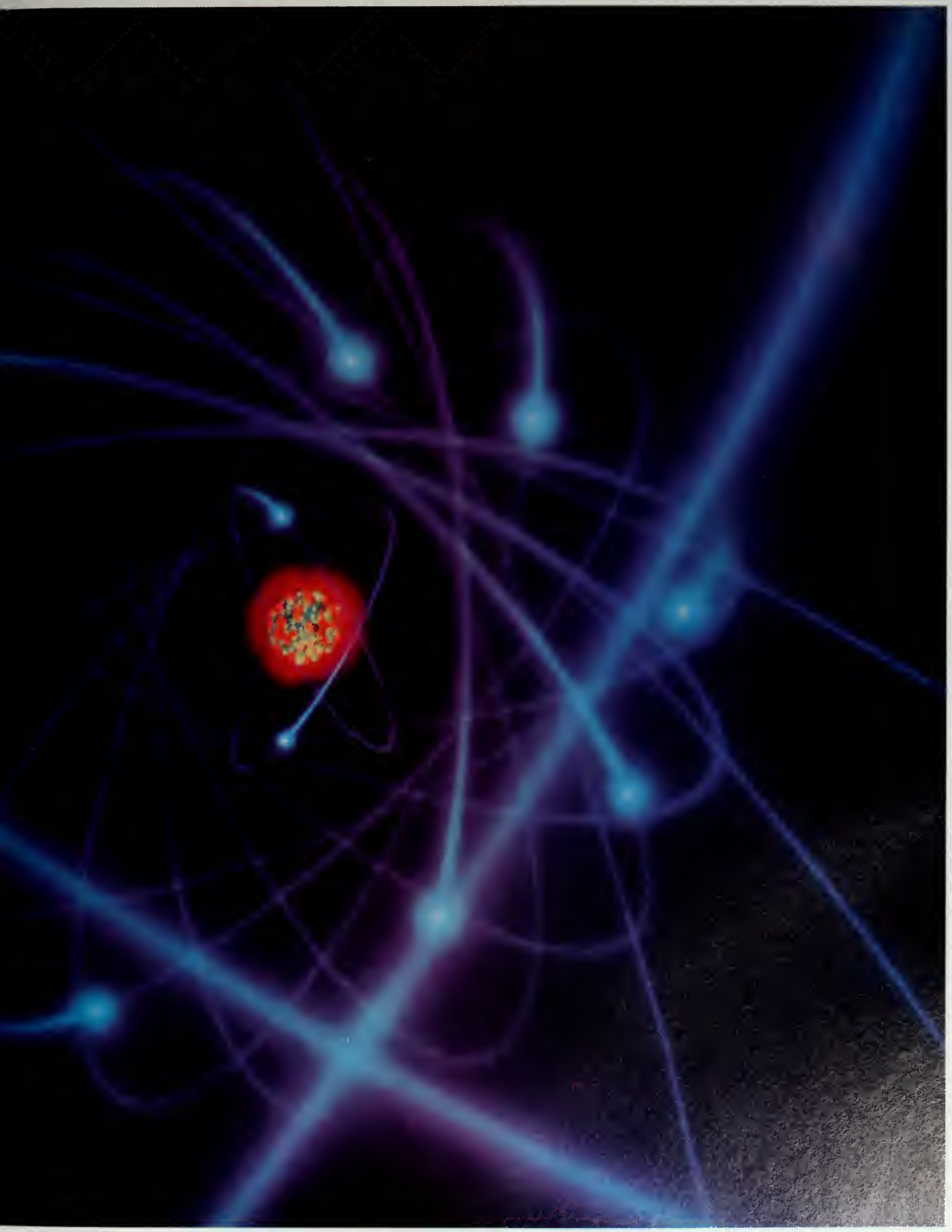
BERYLLIUM



URANIUM

ELECTRONS IN ORBIT

Streaking orbits in these models of five atoms indicate how electron clouds surround the dense central nuclei. Electrons are held in orbit by the electrical attraction between their negative charges and the nuclei's positive protons: one proton for one electron in hydrogen, two of each in helium, three in lithium, four in beryllium and 92 in uranium. All atomic nuclei except hydrogen contain uncharged neutrons.



Chemistry: The Interplay of Matter

In 1960, scientists at the General Electric Company put a lump of peanut butter into an enormous press and subjected it to a pressure of approximately one million pounds per square inch and a temperature of more than 2,000° F. After a time, an amazing transformation took place: the carbon that was contained in the soft peanut butter turned into tiny sparkling diamonds. The feat dramatized a central fact of the science of chemistry—that matter possesses an astonishing ability to take different forms.

Yet all the ordinary forms of matter are built from only 92 distinct types of atoms. These chemical building blocks, the elements, combine and recombine in tight groups called molecules. For the most part, chemistry is the study of the structure and properties of molecules and of ways to take them apart and put new ones together. The work of chemists ranges from the development of pyrotechnic processes like the welding reaction at right to the long and difficult analysis of a protein molecule containing thousands of atoms. From such explorations of matter have come detergents, glues, fertilizers, fabrics, plastics, transistor crystals, drugs and building materials that have remade man's life on this planet.

A FIERY MEETING

Bits of molten metal fly in all directions as two seemingly innocuous substances, iron oxide and powdered aluminum, meet in a clay crucible. This so-called thermite reaction is often employed in welding, because its tremendous heat melts metal almost instantaneously; similar reactions are used to separate metals such as manganese and chromium from their ores.

The Making of a New Compound

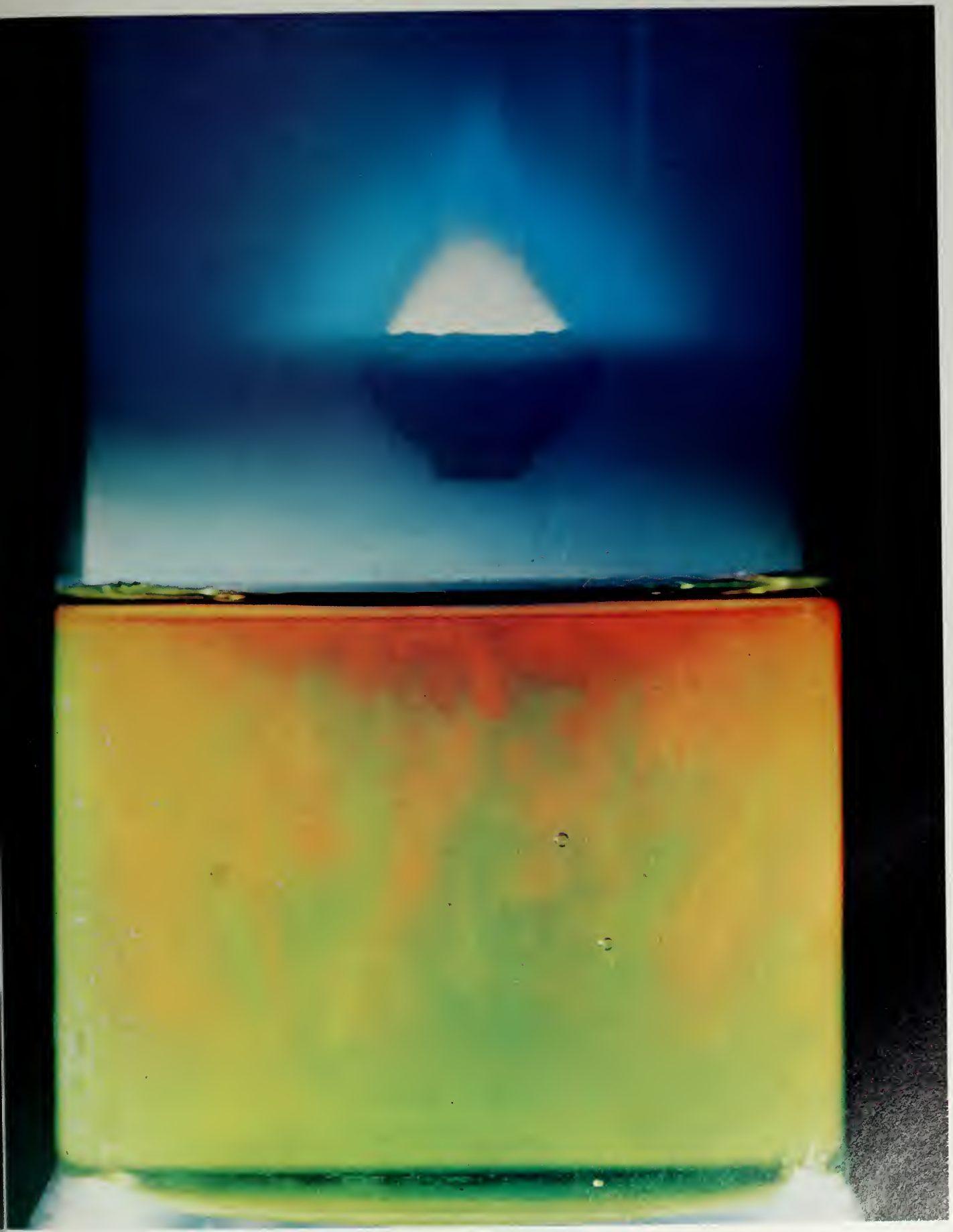
A certain showmanship seems inevitable in the science of chemistry, for matter often changes its structure and properties with sleight-of-hand quickness, sometimes to an accompaniment of dazzling fireworks. At right, for example, two major types of chemical compounds—acids and bases—are shown forming amid a blaze of heat and light. In each case, atoms and molecules collide, join together and create new molecules bearing little resemblance to any of their ingredients. These new molecules are extremely useful: in the United States alone, a substantial segment of the chemical industry's $19 billion annual output consists of acids and bases. About 25 million tons of sulfuric acid, for example, are needed for such purposes as the manufacture of fertilizers, the refining of petroleum, and the removal of rust and impurities from steel. And more than six million tons of one base—sodium hydroxide, or lye —are used in the chemical reactions that produce rayon, soap and paper.

CONSTRUCTING A BASE

A lightweight metal, potassium, reacts with water *(green, right)* to form a basic solution of potassium hydroxide *(purple)*—useful in the manufacture of soaps. Some hydrogen atoms from the water, released as part of the reaction, are ignited by the process and burn as pink-and-bluish gas. Artificial colors in this picture and the one opposite make the reactions visible.

TWO-STEP PROCESS FOR AN ACID

Sulfur burns in air *(opposite)*, uniting with oxygen to form gaseous sulfur dioxide. The gas then dissolves in the water below it and reacts with molecules of water to form sulfurous acid *(orange)*. This compound is useful as a food preservative and in bleaching and brewing.



The Electrical Power of Acids and Bases

Acids and bases are extremely useful to mankind because they produce drastic changes when mixed with other types of compounds or with one another. At first glance, their activity seems similar. A drop of sulfuric acid eats a hole in a lab coat; so does a drop of a base like sodium hydroxide. But even in ancient times, tanners and metalworkers recognized differences between the two classes of compounds. Today the reasons for those differences are known to lie in the composition of their molecules.

Acids are molecules that, on being dissolved, release hydrogen ions—hydrogen atoms bearing a positive electric charge. Solutions of bases also release ions—the negatively charged hydroxide ions, each made up of an oxygen atom and a hydrogen atom joined together. These ions do the work. The positive charge on an acid's hydrogen ion makes it react with metals and other minerals; acids are used to etch metals and clean excess mortar from brickwork. Most minerals are not much affected by the negatively charged hydroxide ions of bases, but fatty substances are; that is why strong bases are used to clear grease from plumbing drains.

To determine concentrations of acids and bases in solutions, chemists use colorful substances called indicators. Changing their shades as the concentration of ions changes, these compounds tell by their hues whether a solution is acidic, neutral or basic *(below)*. Indicators can reveal what happens when an acid is mixed with a base. As negative hydroxide ion meets positive hydrogen ion, the opposing charges balance and the product is neutral *(right)*.

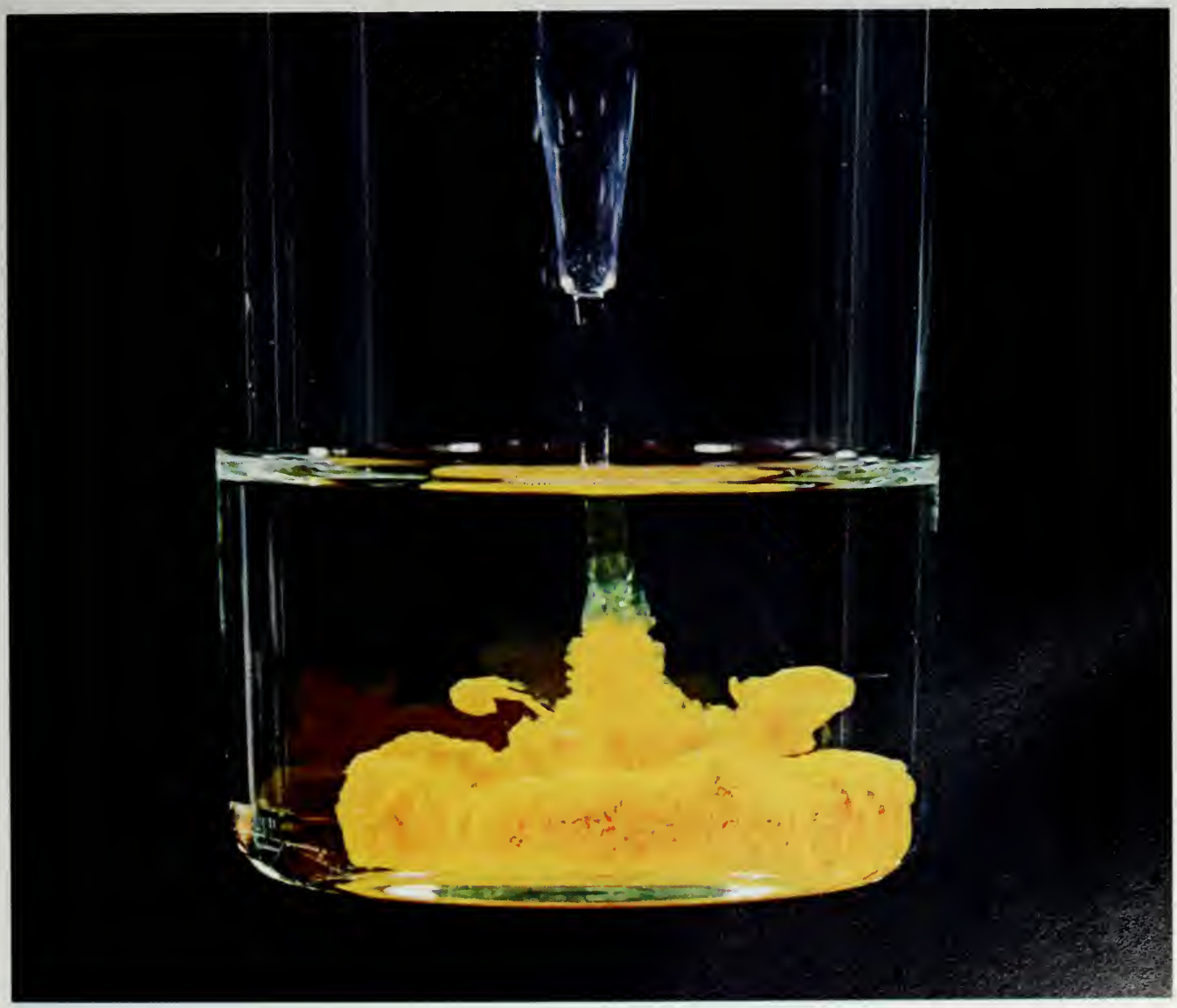
BATTLING TO A STANDSTILL
In the picture at right, areas of color indicate an acid and base meeting and neutralizing one another. Concentrated *(deep red)* and dilute *(yellow)* hydrochloric acid react with sodium hydroxide *(blue)* to produce table salt and water *(green)*, both neutral—neither acid nor base.

A SPECTRUM OF CHEMICAL ACTIVITY
Strong acid to strong base, the relative chemical activities of these solutions are revealed by their colors. Each tube contains an indicator mixture that is red in strong acids and pales to yellow in weak ones. In neutral solution *(center)* it is green; it becomes blue and darkens to purple in the progressively stronger bases.

When Metal Meets Nonmetal

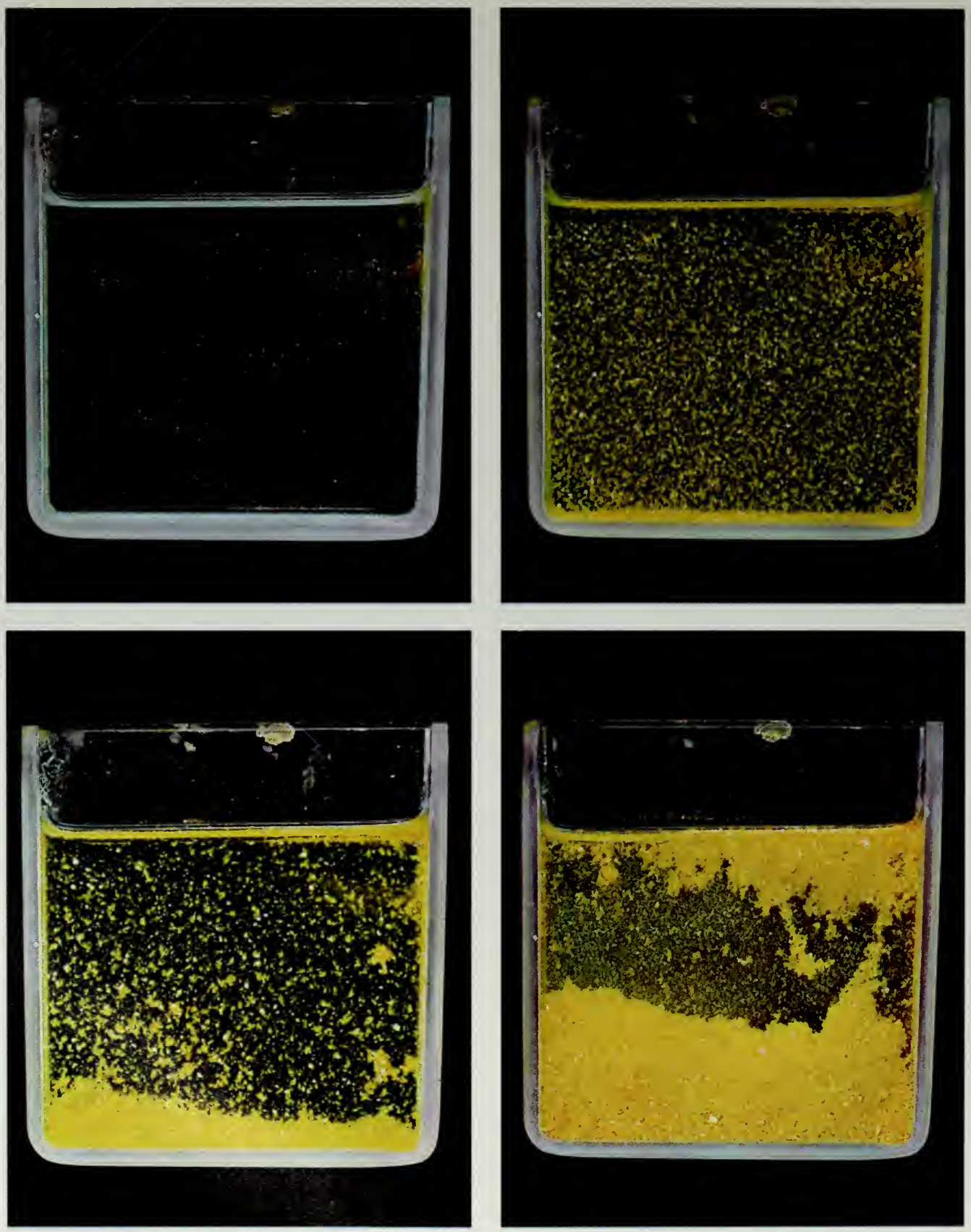
In chemistry, simplicity of molecular structure often goes hand in hand with great industrial versatility. Among the simplest of all chemical compounds are the salts—molecules combining atoms of metals and nonmetals. Salts are easy to make and even easier to find uses for. Cadmium sulfide salt goes into paints; potassium nitrate salt is used for explosives; silver chloride salt helps to build images on photographic film.

Most salts bear no resemblance to the metals and nonmetals they are made of. Locked in the granules of ordinary table salt are two seething demons of the chemical world—the metal sodium and the nonmetal chlorine. Sodium is so violent that it produces a burning reaction when it touches water; chlorine is a poisonous gas. But the molecule that combines these elements is stable and harmless—and industry thrives on it. Each year, 107 million tons of salt are extracted from mines and brines, mostly for industrial processes. For some of these, the molecule is separated into its lethal halves; the sodium and chlorine are then quickly subdued in new compounds, ranging from insecticides to detergents.



A SIMPLE MERGER
In a chemical reaction that resembles a genie rising from Aladdin's lamp, a metal and a nonmetal—aluminum and iodine—combine directly in a glass mortar to form aluminum iodide salt. The heat of the reaction vaporizes some of the iodine, causing particles to rise as a purplish smoke.

PRECIPITATING A SALT
Two salts, both soluble in water, meet and form a new, insoluble salt in the reaction shown above. When a clear solution of sodium sulfide salt is squirted into the glass beaker, it joins with dissolved antimony chloride salt to create a brilliant yellow solid precipitate—antimony sulfide salt



RE-CREATING A SALT CRYSTAL

Crystals tend to reorganize themselves after being broken apart, as shown by the progressive crystallization of lead iodide salt *(above)*. When the solution is hot *(top left)*, molecules of lead iodide are agitated so that they break away from the crystal structures. But as the water cools, the molecules are less energetic and stick together when they come in contact with each other, forming ever-larger lead iodide crystals.

GROWING CRYSTALS OF TIN
When a tin rod is dipped into an acid solution of tin chloride salt *(above),* whiskerlike crystals of metal slowly grow from the rod's surface. The tin in the salt solution leaves the solution and sticks to fellow atoms on the rod's surface, building up the filaments of pure tin crystals.

Molecules in Orderly Array

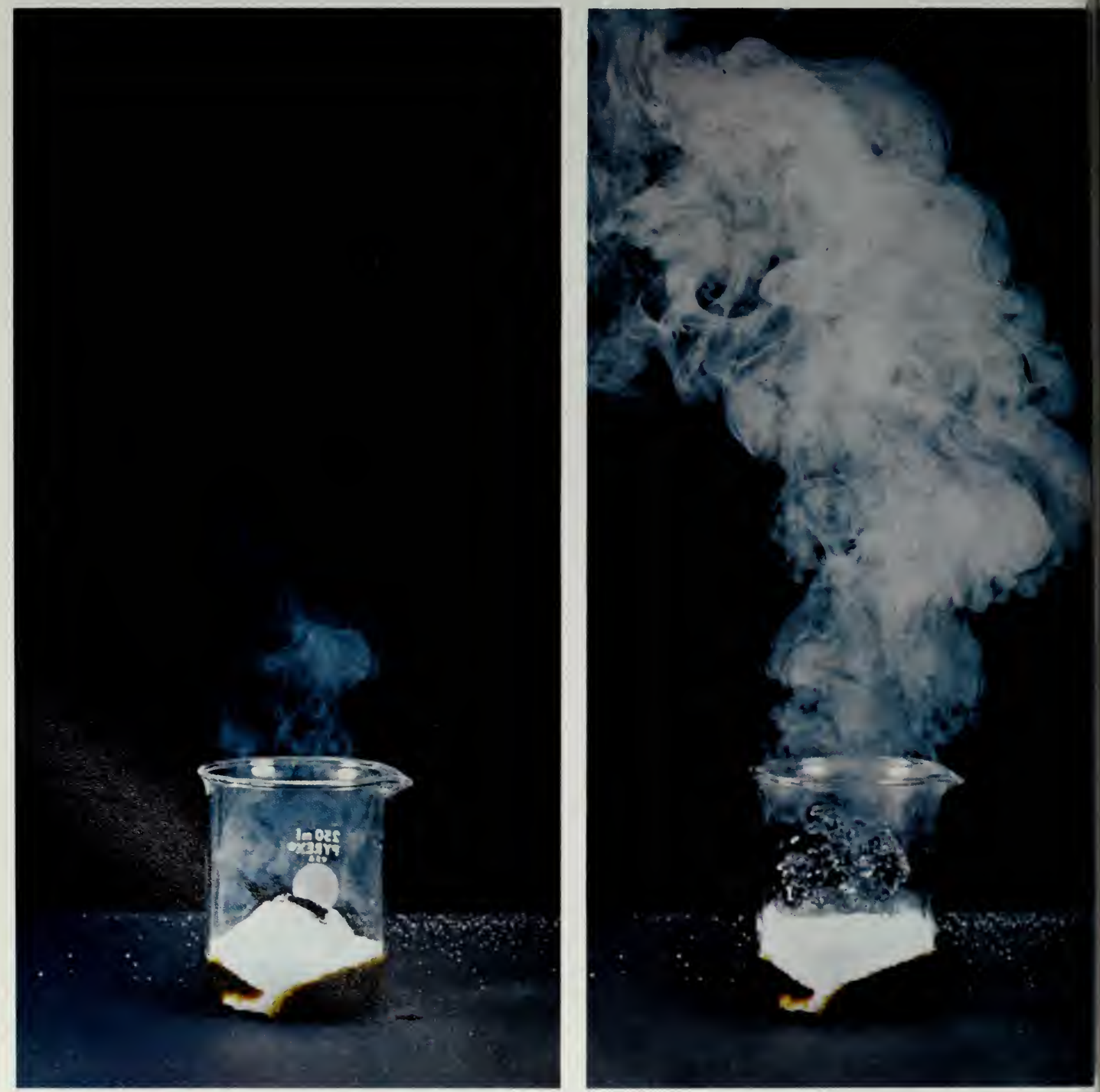
The picture at left gives a glimpse into the way atoms and molecules are put together by nature in the substances we use. In the photograph, the filaments sticking out from the rod consist of large crystals of pure tin. The shape of each crystal is normally the same—long and pointed in tin at ordinary temperatures—a form that reflects the layout of invisibly small tin atoms within the solid material and gives it many of its properties.

Every true solid, like tin, is made up of more or less uniform crystals, which are ordinarily too small to be seen without a microscope. Inside these crystals, the atoms and molecules are fixed in an orderly array, like bricks in a wall. And like a wall, the crystal owes its strength to the interlocking arrangement of its parts. Because most natural crystals are small and blemished by impurities, they and the bulk materials they make up are weaker than they otherwise might be. But today large, very pure —and therefore very strong—crystals can be "grown" in the laboratory *(left).* An extremely pure crystal of iron, for example, has a tensile strength more than 50 times greater than that of the best cast iron.

Oddly enough, the one material that is most often called "crystal"—glass—is not crystalline at all. Glass is one of the few rigid substances whose molecules are fixed, not in an orderly structure, but in an entirely helter-skelter arrangement. Now, however, crystalline glass has been made at the Corning Glass Works. Because of its ordered pattern of molecules, it is harder than steel, lighter than aluminum and so resistant to heat that it provides an excellent material for rocket nose cones.

The Vital Carbon Compounds

Carbon has been called the "wonder element"—and with good reason. Its atomic structure enables it to link up, both with itself and with other elements, in an enormous variety of chain or ring formations. In linkages with hydrogen alone, for example, carbon compounds run into the thousands, from methane gas (one carbon atom, four hydrogen atoms) to



When ordinary table sugar—made of carbon, hydrogen and oxygen—is mixed with concentrated sulfuric acid, its oxygen and hydrogen atom

polyethylene (200,000 carbon atoms, 400,002 hydrogen atoms).

In one way or another, the compounds of carbon play key roles in human life. For one thing, most molecules containing carbon can burn in combination with oxygen, and thus make excellent fuels. Some of these fuels are obvious and well known: wood, natural gas, coal, oil. Others are more subtle but even more important: the human body is fueled by simple carbon compounds called sugars, starches and fats, extracted from food. (A laboratory demonstration of the breakdown of a sugar is pictured below.)

Most significant of all is carbon's role in living things. Every living organism is made up of carbon compounds; even the major sources of industrial carbon, coal and petroleum, are derived from the long-dead bodies of plants and marine animals. So closely bound up with life is this element that the study of its compounds is called *organic* chemistry—and organic chemistry, which is only a little more than a century old, is one of the most active branches of the science.

e released to form water, leaving a mound of carbon behind. Most of the water is turned into a cloud of steam by the heat of the reaction

The Proteins: Molecules of Life

According to one theory, life began to develop in a chemical synthesis performed about four billion years ago. The laboratory retort was the ocean—then a warm flood covering the earth and bombarded by lightning and harsh ultraviolet rays. The raw materials were ammonia, methane and hydrogen—dangerous gases that, along with water vapor, made up the atmosphere. Over the eons, this combination of chemicals, electricity and radiation produced organic substances called amino acids. Eventually, the acids linked together to form molecules called proteins, built up of long coiled chains of carbon, hydrogen, oxygen and nitrogen.

All living things contain these remarkable molecules. And although most protein molecules can be built from different combinations of just 20 different amino acids, they display a bewildering diversity of form and function. Proteins make up fingernails and flesh, hair and muscle fibers, and the hemoglobin in red blood cells. The enzymes that control the chemical reactions inside a living organism are mainly proteins. And even the chromosomes that dictate the production of bodily proteins, setting the hereditary patterns of life, contain proteins themselves.

EGG PROTEIN, HARD BOILED
Each protein molecule in egg white consists of spiral chains of amino acids, folded in a globular mass. Normally, the protein takes the form of a thick solution, because the surface of the molecule links up with water molecules. But boiling water *(right)* opens up the protein molecule, exposing atoms that are repelled by water and causing the egg white to clot and harden.

Microbiology: The Smallest Living Things

On June 10, 1675, the developing science of biology strayed over a frontier and found itself in a land of mysteries beyond counting. That day, a Dutchman named Anton von Leeuwenhoek looked at a drop of clear rainwater through a homemade lens—a simple microscope. "I had no notion that I would see any living creatures," he later wrote in his diary, "but on examining it I saw with wonder fully a thousand living creatures in one drop of water." Leeuwenhoek had given biology a new world to study. It turned out to be a world of microscopic organisms that spoil food and turn fruit juices into wine, that rot fabrics and dispose of organic wastes, that make man sick and manufacture drugs to cure him.

These tiny organisms, the microbes, exist in many forms. Leeuwenhoek himself saw the one-celled protozoa and the smaller organisms called bacteria. But not until 1939 were microbiologists able to visualize the structure of the viruses, which are little more than large molecules on the borderline between animate organisms and inanimate matter. Today the search for microbes—in the air, in soil, in water, in animal and plant tissue—is throwing new light on the smallest of living things and their enormous power to help or harm mankind.

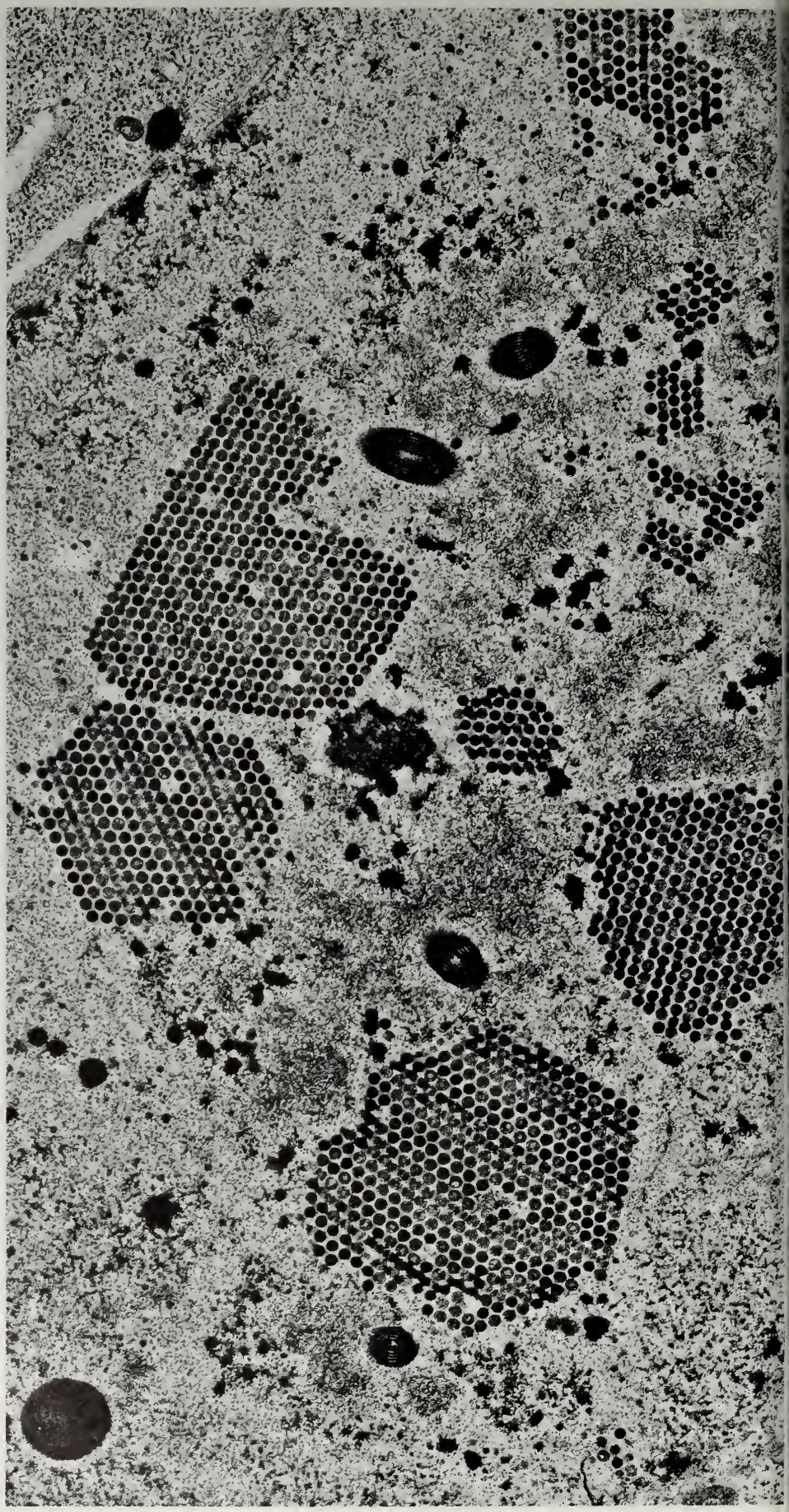
A MINUSCULE HUNTER

In a droplet of pond water, a wealth of life—algae, bacteria and small protozoa—surrounds a relatively huge Stentor protozoon *(opposite)*. Actually, the one-celled Stentor is only .04 inch long—but it is a formidable foe of the smaller organisms near it. With a set of hairs on what looks like a head, the Stentor flails the water and brings food close to be engulfed.

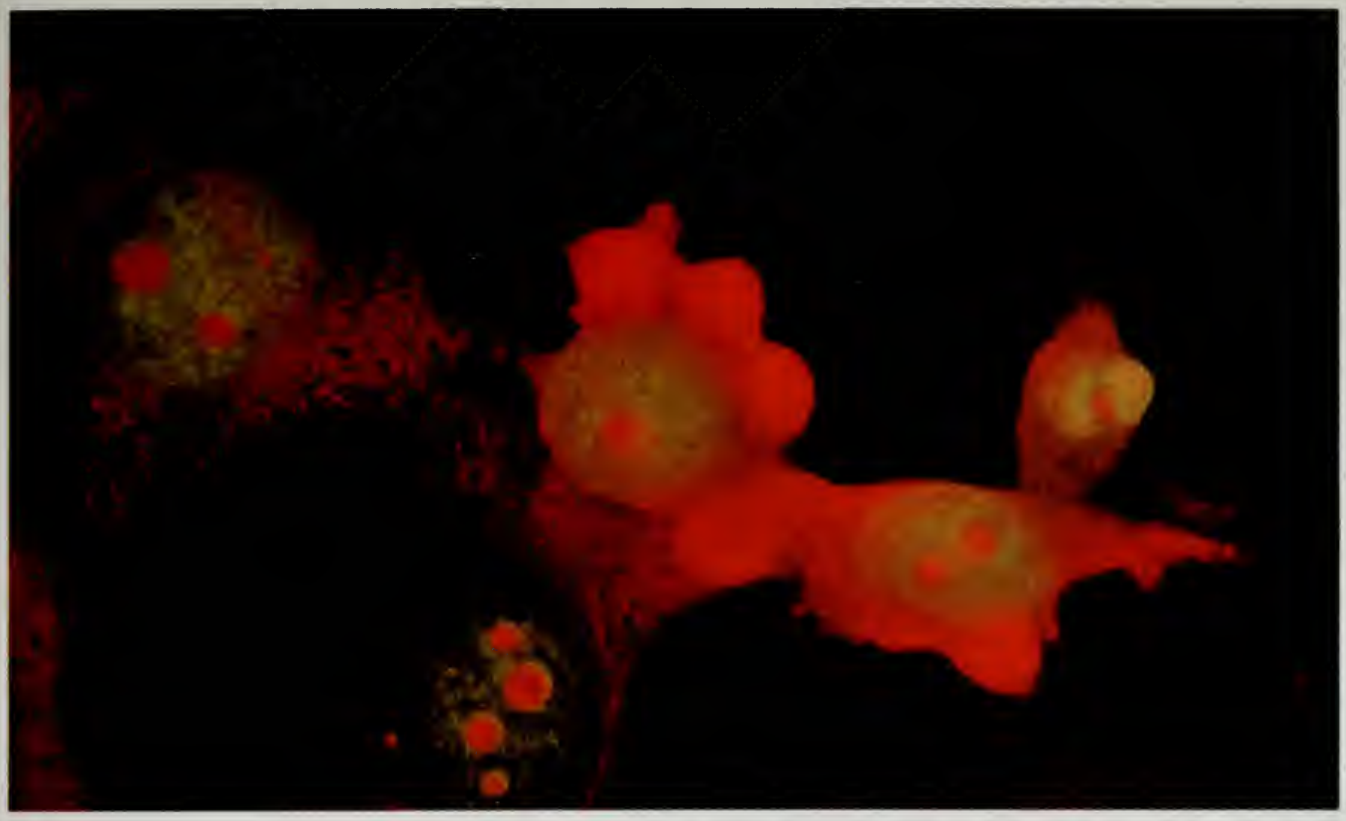
A Molecule Comes to Life

Somehow—no one knows precisely how—certain specific combinations of protein molecules and nucleic acid form a virus, the bridge between the inanimate and the animate. These molecular combinations are incredibly small—some of them are barely one millionth of an inch across. A virus can attack a living cell and "order" it to manufacture more protein and nucleic acid molecules, which in turn can combine into virus particles. This multiplication phenomenon falls somewhere between simple chemical reactions and true reproduction—and makes viruses some of the most dangerous enemies of man.

Isolated in a test tube the virus—a protein shell surrounding a single molecule of nucleic acid—is as lifeless as any other chemical. But in a living body it destroys its victim cell by cell, as shown opposite. Once a virus has invaded a cell, it multiplies by utilizing the cell's energy and materials. The newly formed viruses may be expelled by the cell; alternatively, as the viruses increase in number the cell wall may weaken and collapse, permitting the viruses to attack other cells and destroy them.

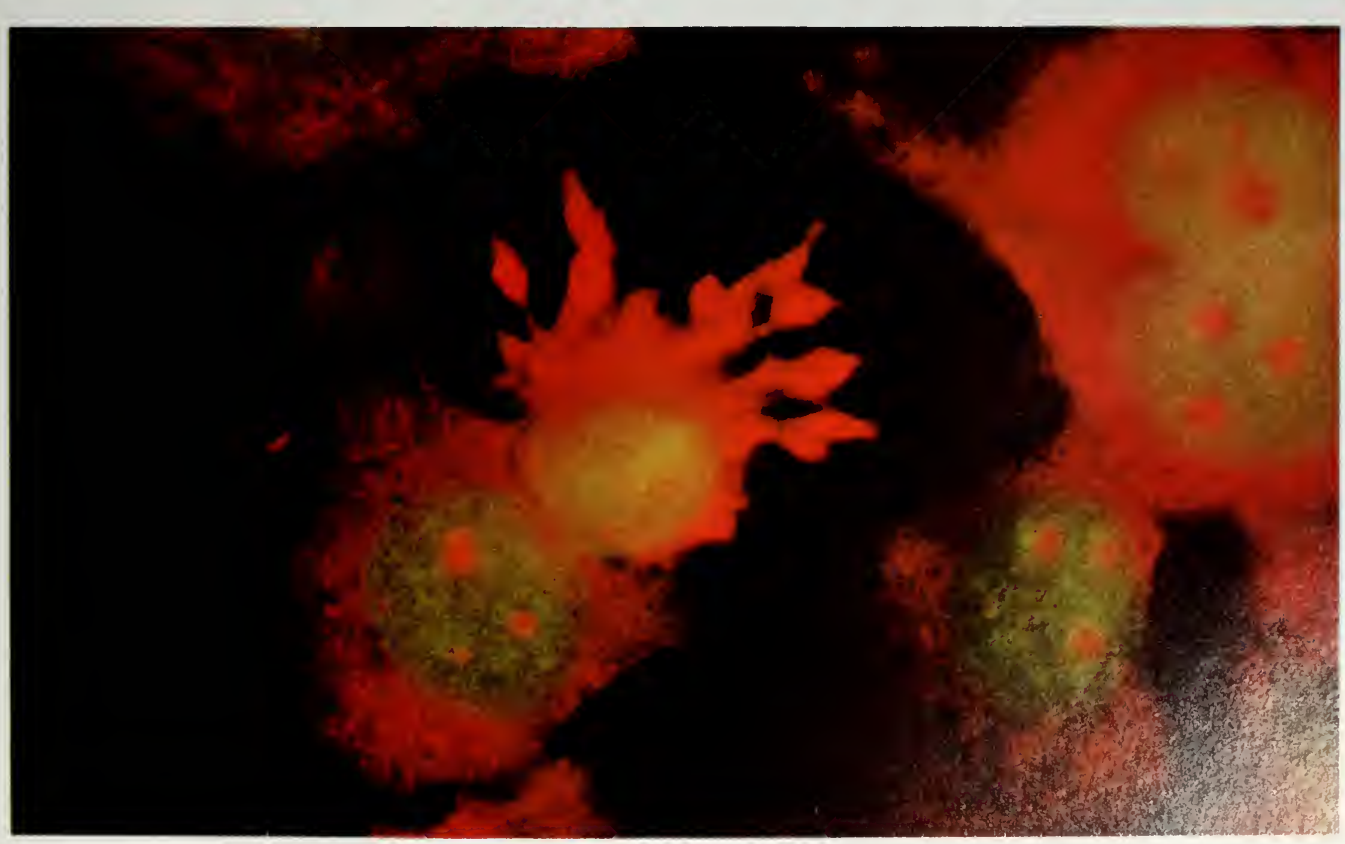


NEATLY PACKED VIRUSES
Magnified 30,000 times by an electron microscope, respiratory-disease viruses are shown grouped in a honeycomb pattern. The formation results from the identical and symmetrical 20-faceted molecular structure of the viruses.



A VIRUS BOOM

Measles, a common childhood disease almost everywhere in the world, is caused by a type of virus less than eight millionths of an inch in diameter. These photomicrographs of measles viruses, taken with a conventional microscope, show large agglomerations, not single viruses, since only an electron microscope is powerful enough to show individual viruses. Above, the viruses *(orange bulges),* manufactured within the cells, crowd around the cell nucleus *(green).* Eventually, the cell breaks open *(below),* releasing the viruses to attack still other cells.

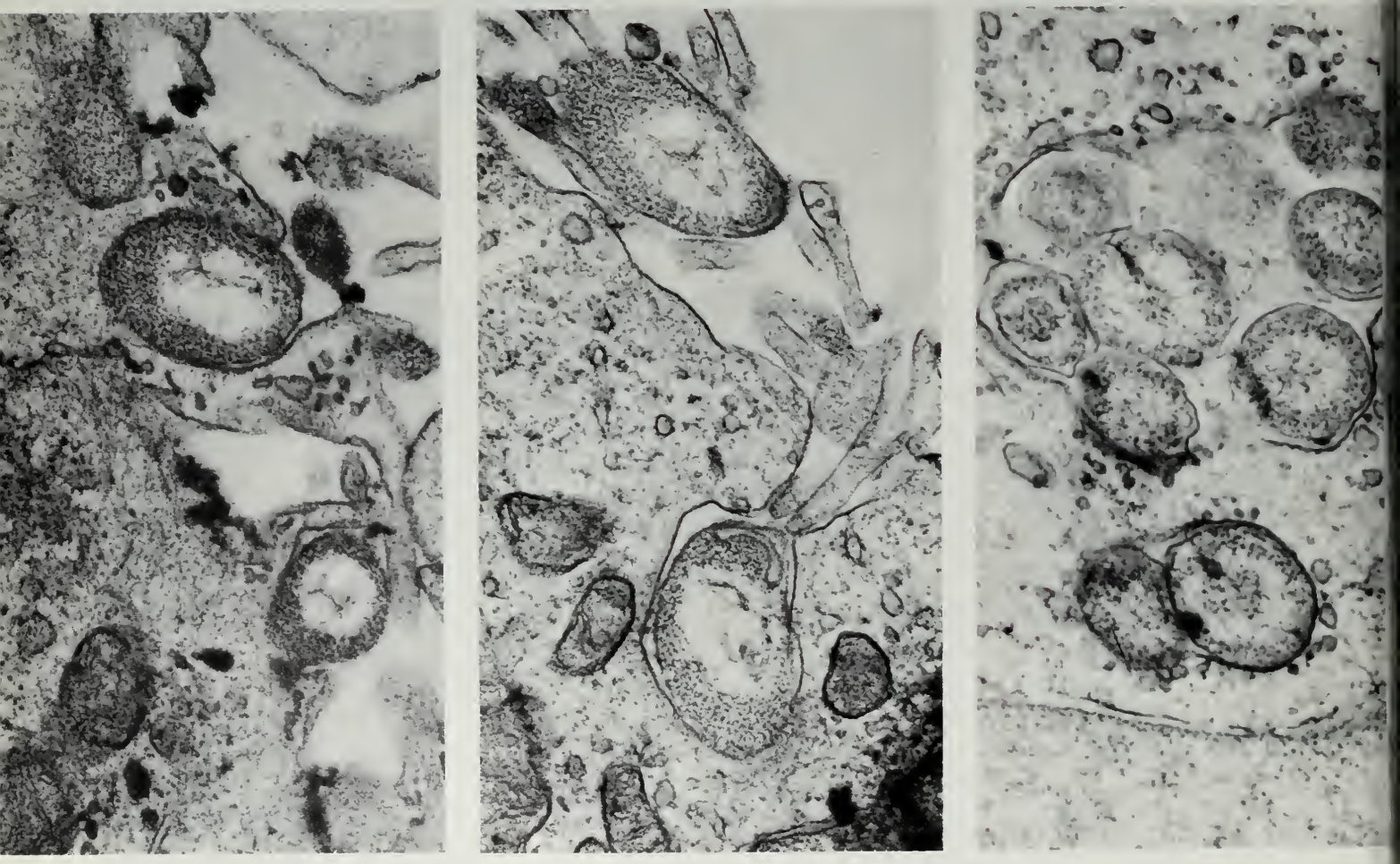


The In-between Microbes

Some of the most vicious agents of human disease belong to a poorly understood category of microbes, larger than viruses but generally smaller than bacteria, and falling somewhere between the two in behavior. One of these mysterious microbes, a rickettsia, causes typhus fever. Carried by body lice, it has in the past decided wars and influenced the course of history by decimating armies and whole populations. A microbial cousin of the rickettsia, called the trachoma agent, has an even darker record. It is responsible for a blinding eye disease that today afflicts 500 million of the world's people.

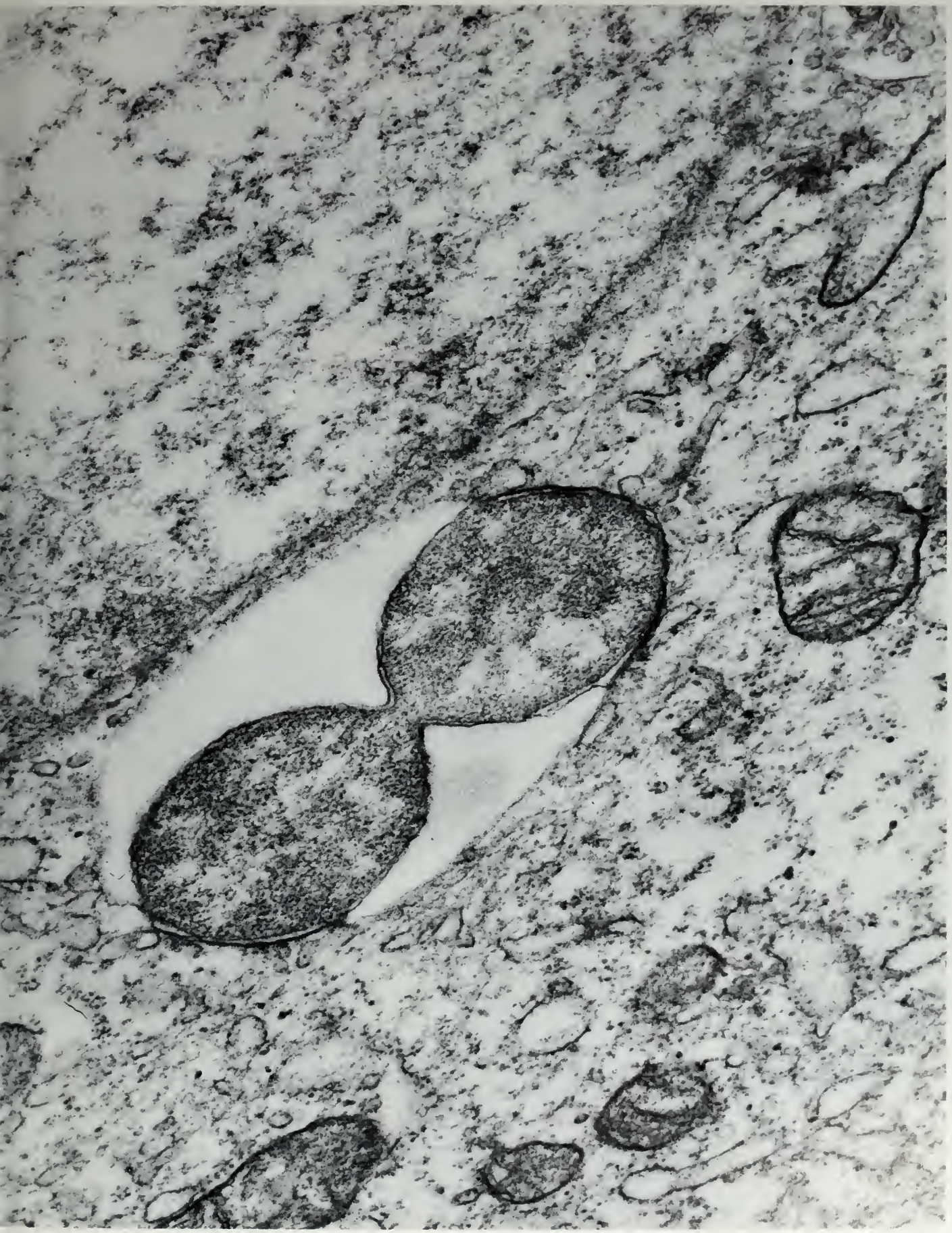
The life of the trachoma microbe is illustrated on these pages. Along with the rickettsia, it resembles a virus in one major respect: the trachoma microbe is not itself a living cell, for it can reproduce only within cells. However, a true virus forces a cell to manufacture new viruses, while the trachoma agent reproduces in a more familiar way by dividing and redividing *(right)*. Another factor distinguishes the trachoma microbe from a virus: like the bacterium, it is vulnerable to treatment with antibiotics; none of the antibiotics thus far discovered have been effective against true viruses.

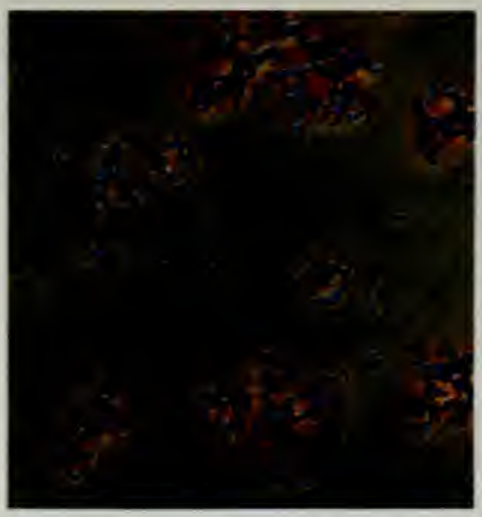
The odd behavior of the trachoma agent is the subject of intense research by microbiologists, especially in the Orient, where trachoma takes its highest toll. The figures available indicate that at least 100 million Chinese have had it in severe form, and some 20 million are practically blind.



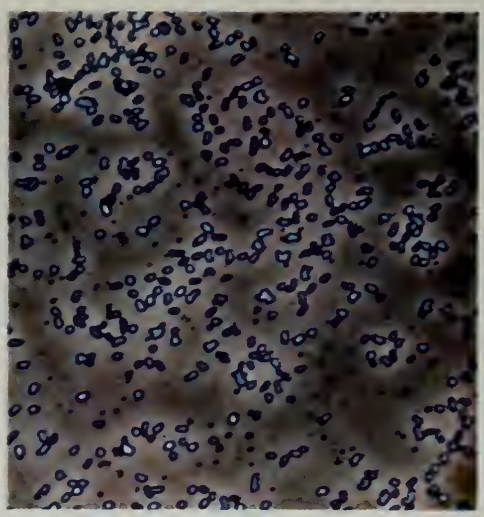
AN ATTACK OF TRACHOMA

Trachoma begins with an inflammation of the victim's eyelid and may end in severe damage to the cornea—the outer coat of the eyeball. As seen in a series of photomicrographs *(above)*, the disease begins its onslaught as oval trachoma microbes come into contact with the surface of a cell *(left)*. Two hours later, the cell is engulfing the lethal microbes as if they were particles of food *(middle)*. About three hours after absorption, the trachoma microbes have traveled deep into the cellular fluid *(right)*, and are swiftly consuming the cell's internal matter. Approximately 10 hours later, the microbes begin to reproduce by the process of division *(opposite)*. Eventually, the cell will become so crammed with the trachoma organisms that the cell's wall crumbles. Then liberated microbes, greatly increased in number, move on to infect other cells with the blinding disease.



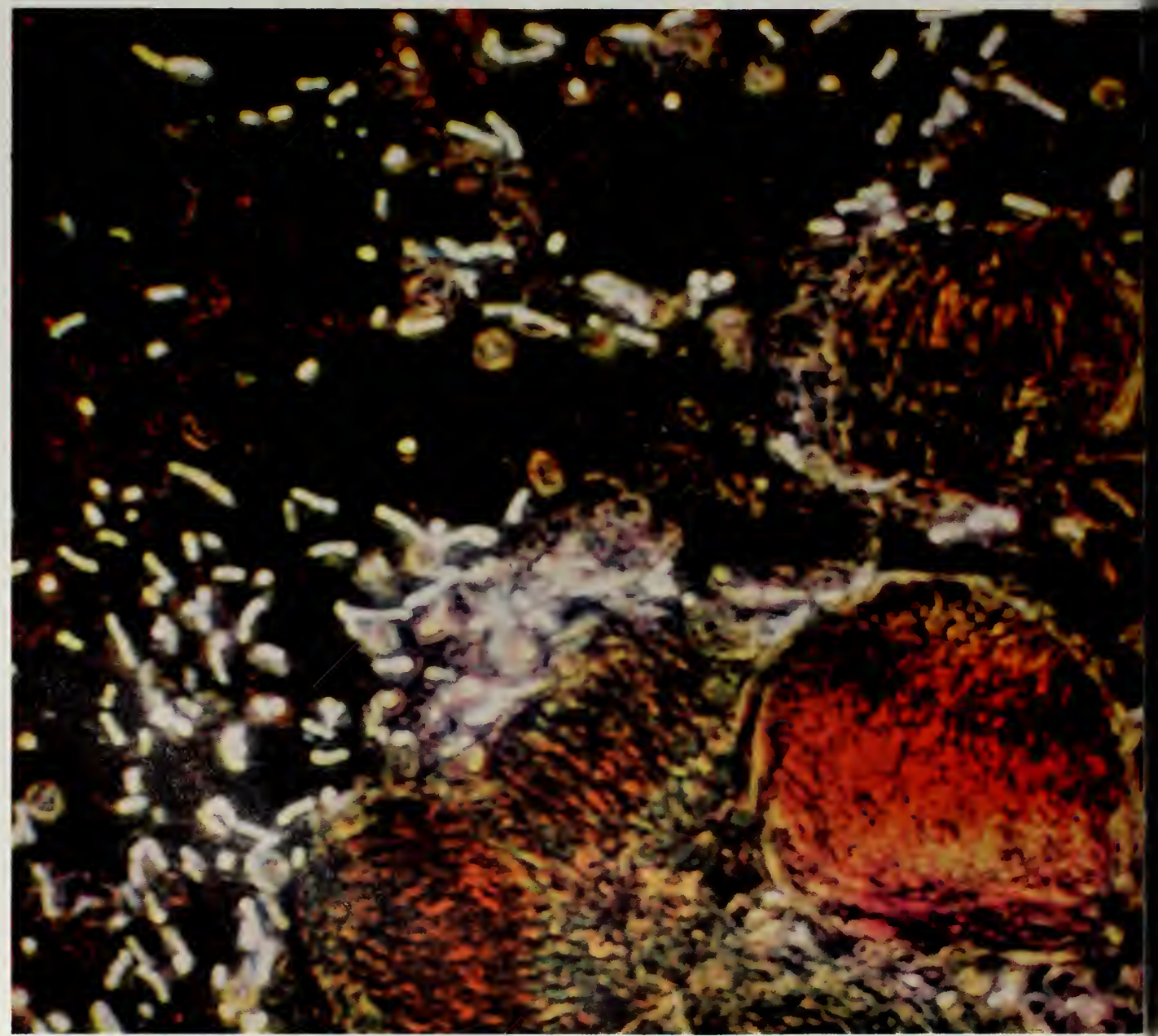


(B) DIPLOCOCCUS PNEUMONIAE



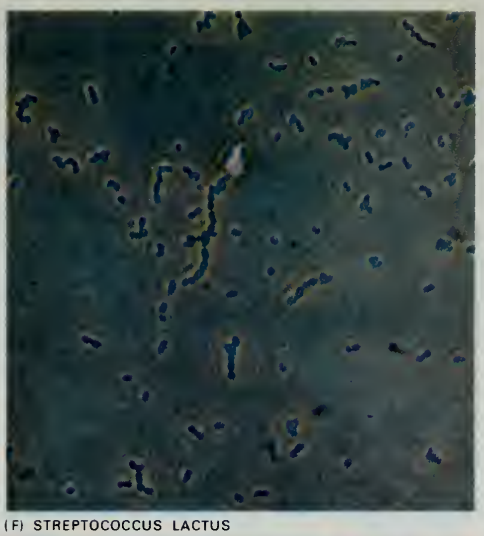
(C) SALMONELLA ENTERITIDIS

(D) RHODOSPIRILLUM RUBRUM

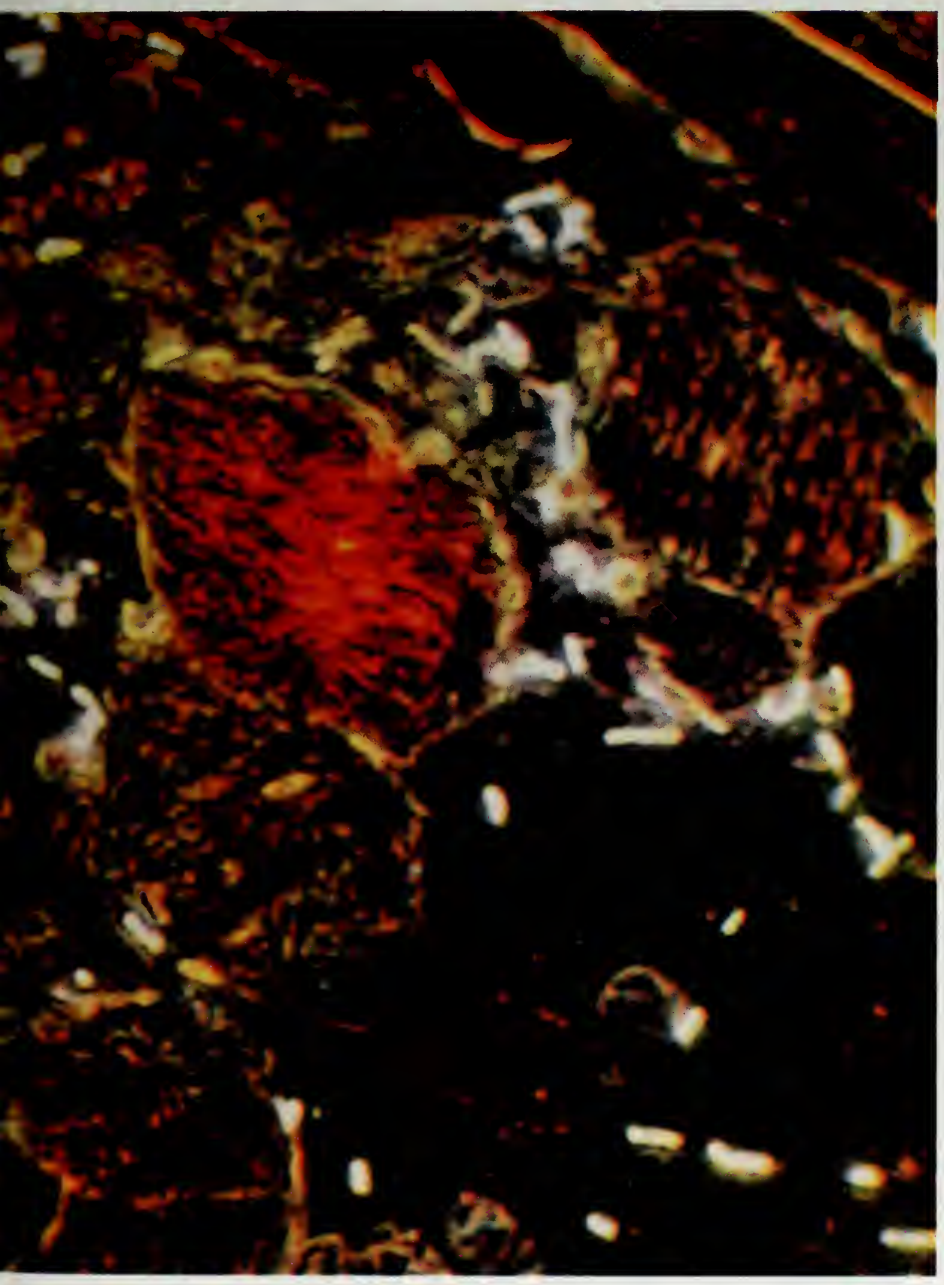


(A) BACILLUS ANTHRACIS

(E) LACTOBACILLUS ACIDOPHILUS



(F) STREPTOCOCCUS LACTUS



Microscopic Friends and Foes

The smallest self-sustaining microbes —usually no more than 1/10,000 of an inch across—are the bacteria, one-celled plants that absorb food from their environments and reproduce by dividing into two organisms. These are the smallest organisms that Leeuwenhoek could see; and even with his primitive microscope, he was able to distinguish all three major types of bacteria, to which scientific names were later given: round *(coccus)* rod-like *(bacillus)* and spiral *(vibrio, spirillum* or *spirochete,* depending on the degree of spiraling and flexibility).

Today, some 1,500 different species of bacteria are known. The photomicrographs at left and opposite show the shapes of representative types of these organisms. Among the most familiar are the relatively few that inflict illness or death on animals and human beings. *Bacillus anthracis* (A), the white bacilli seen swarming among an animal's muscle cells, were the first microbes proved to cause disease—anthrax. *Diplococcus pneumoniae* (B) got its name from the lung disease it causes—pneumonia, from the Greek *pneumon,* or "lung"; *Salmonella enteritidis* (C), the short, thick bacillus, causes food poisoning.

Many bacteria, on the other hand, are harmless or even helpful to man. Some, like *Rhodospirillum rubrum* (D), appear to do neither good nor harm. Others are useful to man's industry. *Lactobacillus acidophilus* (E) helps make a fermented milk; *Streptococcus lactus* (F) curdles milk to make cheese; and still other species change cabbage into sauerkraut, make wood alcohol and help tan leather.

Giants in a Small World

The one-celled animals called *Protozoa* (from the Greek word for "first animals") are the giants of the microbe world. Ranging from less than 1/10,000 of an inch to a few inches long, each single cell performs all of the vital functions for which larger animals require billions of cells.

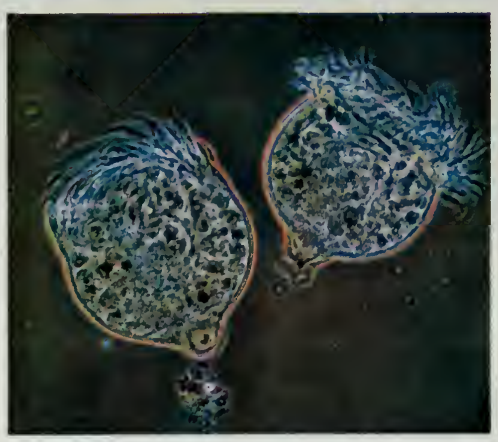
Most protozoa live harmlessly in oceans and ponds. However a few live as parasites within larger animals and can cause some of mankind's most disabling diseases. Some species, for example, attack the human digestive tract to cause dysentery. Others, which multiply in the bloodstream, cause malaria, the world's most widespread disease.

In the photomicrographs at right and opposite, five harmless protozoa display the variety of forms assumed by these tiny animals. The aquatic *Ceratium* (A) has proved useful to scientists because the length of its three arms varies with the saltiness of the water in which it lives, thus affording a rough measure of salinity.

All of the remaining pictures show species of the most highly developed protozoa—the ciliates, named for the hairs, or cilia, they use for swimming and gathering food. Barely visible around the slender *Dileptus* (B), these hairs form a ring around the mouths of the *Vorticellae* (C) and are seen in motion in two *Blepharismae* (D), pictured next to a single human hair. The detailed view *(opposite)* shows one of the largest and most common of the ciliates, a *Paramecium* (E) surrounded by spikes discharged from its own body. Though paramecia have been studied for many years, scientists are still uncertain whether these spikes are for protection or to anchor the animal while feeding.

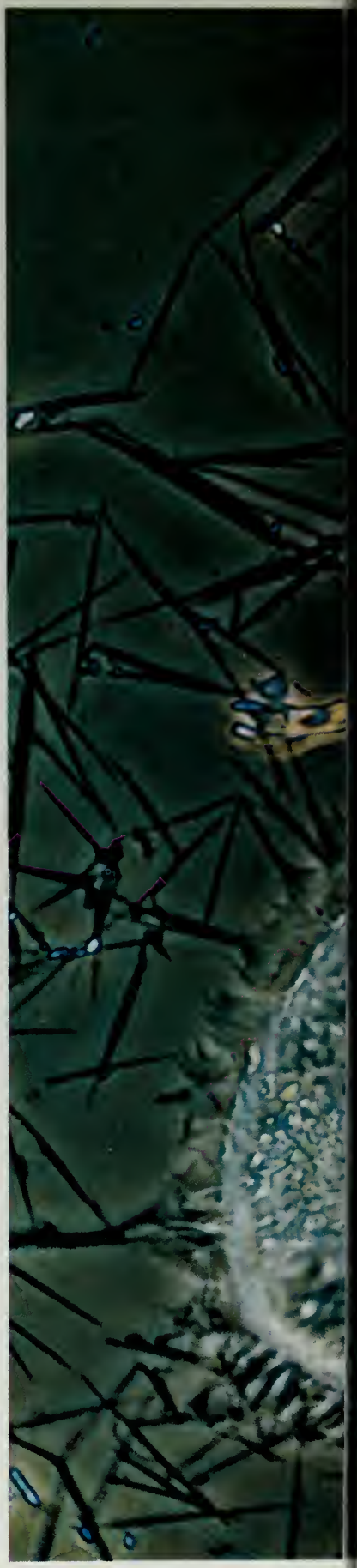
(A) CERATIUM

(B) DILEPTUS

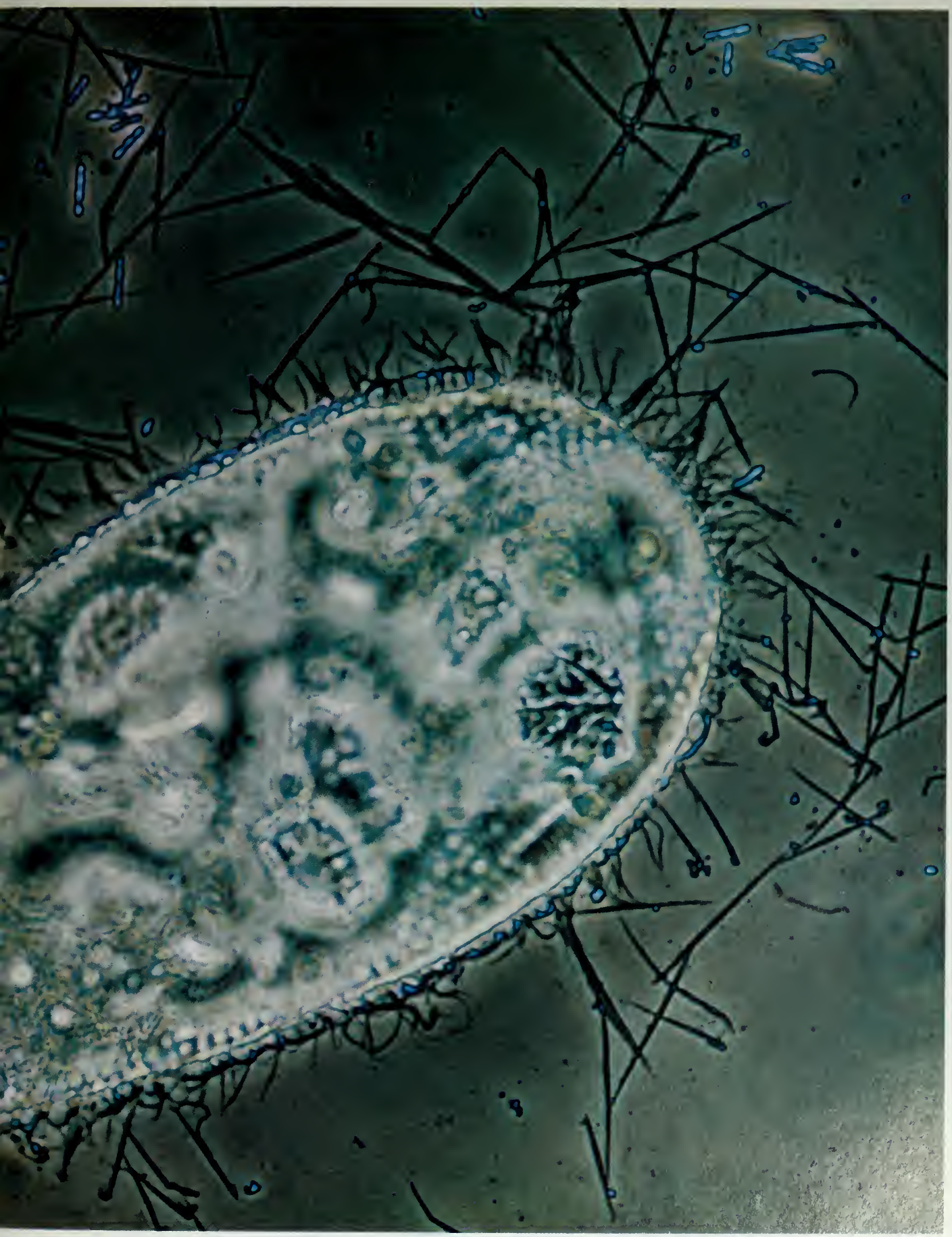


(C) VORTICELLA

(D) BLEPHARISMA



(E) PARAMECIUM



Anatomy: Designs for Life

During the last two billion years living creatures have developed an enormous number of ever-more-complex forms that make them at home in every niche of the world. Animals, having conquered the sea from top to bottom, climbed onto the land, took to the air, and even colonized such specialized environments as the intestines of other animals. Today, the gallery of living animals exceeds the bounds of any plausible Noah's ark or any single book: the earth contains at least 1.2 million different species, ranging from parasites 1/12,000 of an inch long to whales that measure 113 feet and weigh 170 tons. Despite the awesome variety of living forms, one branch of science—called comparative anatomy—reveals the underlying orderliness of life.

"As different as cats and dogs," contains this paradox. For cats and dogs—two distinct species of mammals—have very similar anatomical structures for digesting food, circulating blood and supporting tissues with bone. Such resemblances exist throughout the animal world: a man's arm is related to a crocodile's foreleg and a bird's wing; and the nerves of a hydra can be recognized as forerunners of the specialized odor-sensitive cells in the nose of a salamander *(right)*.

A WIDELY SHARED SENSE

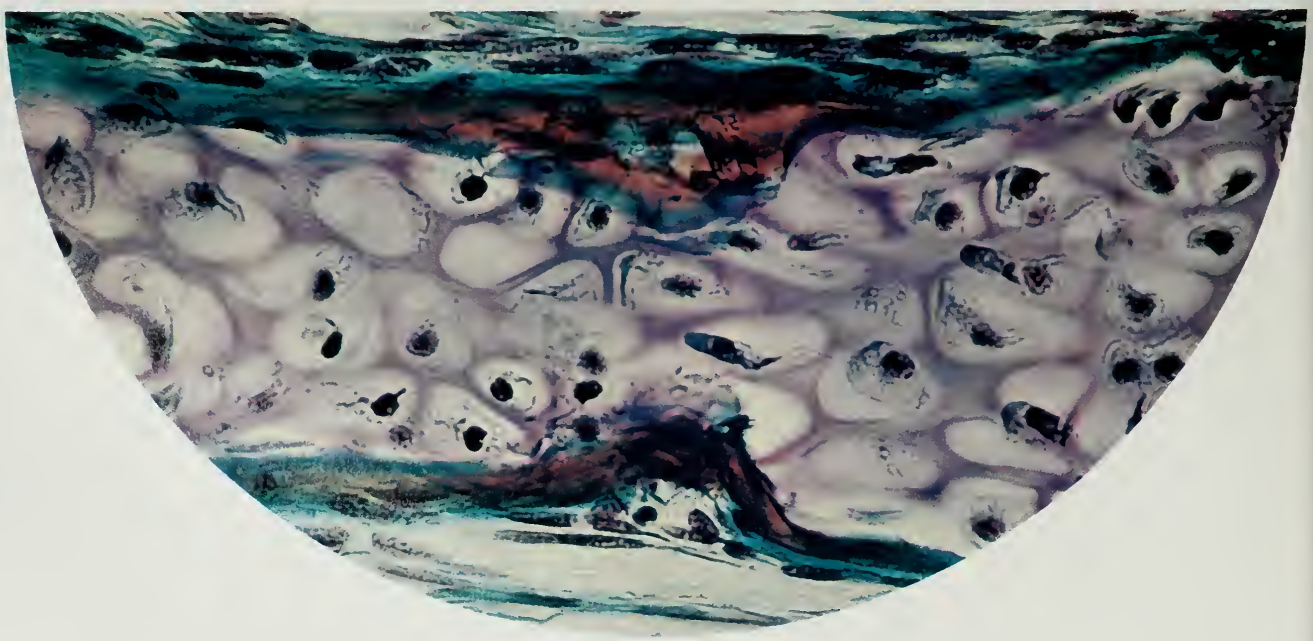
Whitish nerve cells in the nose of a salamander react to the chemical differences among substances reaching their moist surface—that is, they respond to smells. Almost all animals, from fish to men, have similar nerve endings, which reach their highest development in those mammals that can detect and identify an enemy, a mate or food by smell alone.

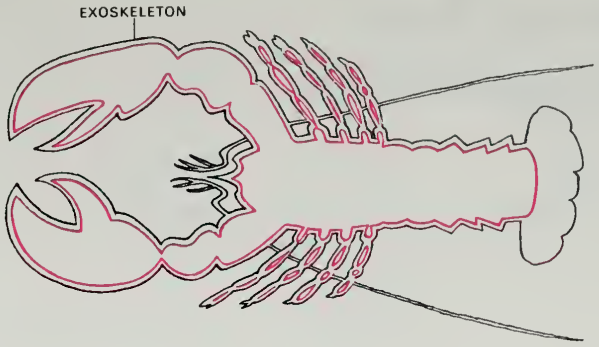
Skeletons for Support

Eminently practical in its inventiveness, the process of evolution rarely builds a better mousetrap from scratch. In effect, evolution keeps old mousetraps, and slowly alters the designs to fit new jobs. For instance, a lobster supports its tissues by secreting a hard shell *(below, top)*—and the same scheme, called an exoskeleton, in some 965,000 versions supports such lightweight bodies as those of bees, snails and centipedes.

Sometimes, however, evolution takes a new road. The exoskeleton would be an inadequate framework for larger animal bodies, and for them a different scheme has evolved—a skeleton that grows internally *(below, bottom)*. First found in small sea creatures, modifications of the skeleton enabled pre-amphibians to crawl onto the land about 365 million years ago—the breakthrough that led to an enormous wealth of land animals.

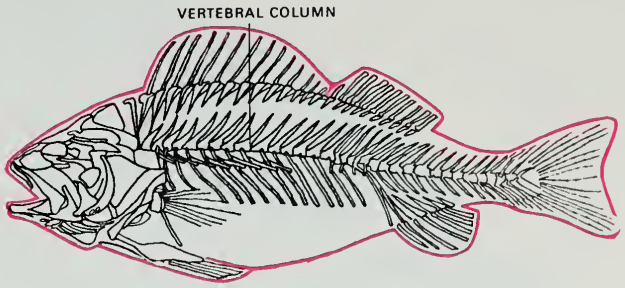
Above: A photomicrograph shows cells of a crab *(dark purple)* that pass calcium salts to the exoskeleton *(purple)*, hardening it. Below: A microscopic view of a frog's limb shows orange-colored borders of bony material growing around softer cartilage cells.



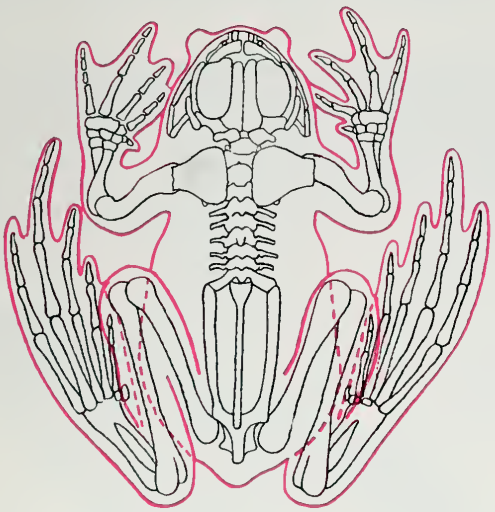


THE LOBSTER'S EXOSKELETON
The lobster's exterior skeleton *(right)* is perfectly adapted to its needs. The hard skeletal shell is segmented and has muscles attached to its inner side, permitting the lobster to crawl rapidly along the sea bottom, scavenging for food. And as its body grows, the lobster periodically sheds its old shell and forms a new and larger one.

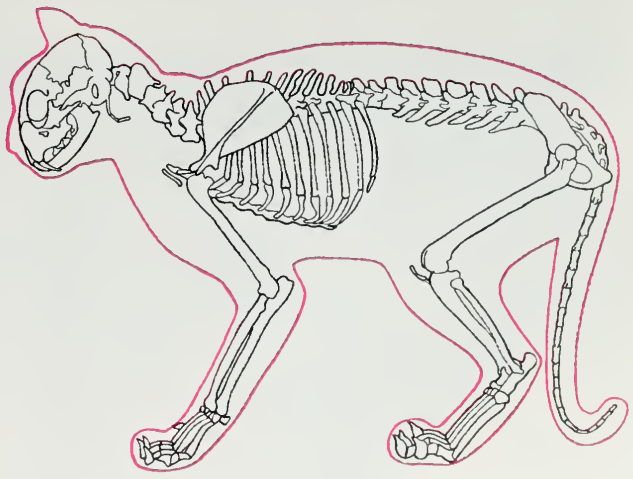
BEGINNINGS OF A NEW DESIGN
A primitive example of an internal skeleton is found in a two-inch-long aquatic animal called an amphioxus, which has a rod of jelly-like cells enclosed in a sheath of tough fibers. Highly flexible, yet strong enough to support the amphioxus' body, this rod—the notochord—is the forerunner of the backbone of all higher animals.



ELABORATE STRUCTURE IN A FISH
Once the perch, a typical "bony" fish, emerges from the embryo stage, its notochord is incorporated into a true vertebral column. Numerous ribs support its muscles, and many small skull bones support and protect its brain tissue. Since its body is buoyed up by water, the perch's bones are fragile compared to those of a land animal.



STRONGER BONES FOR LIFE ON LAND
Amphibians, of which the frog is a familiar example, were the first animals with internal skeletons strong enough to support their bodies on land, without the help of water to buoy up their weight. Because the frog's leg bones project sideways, the animal can hop but cannot walk, and so stays close to water, in which it is very mobile.

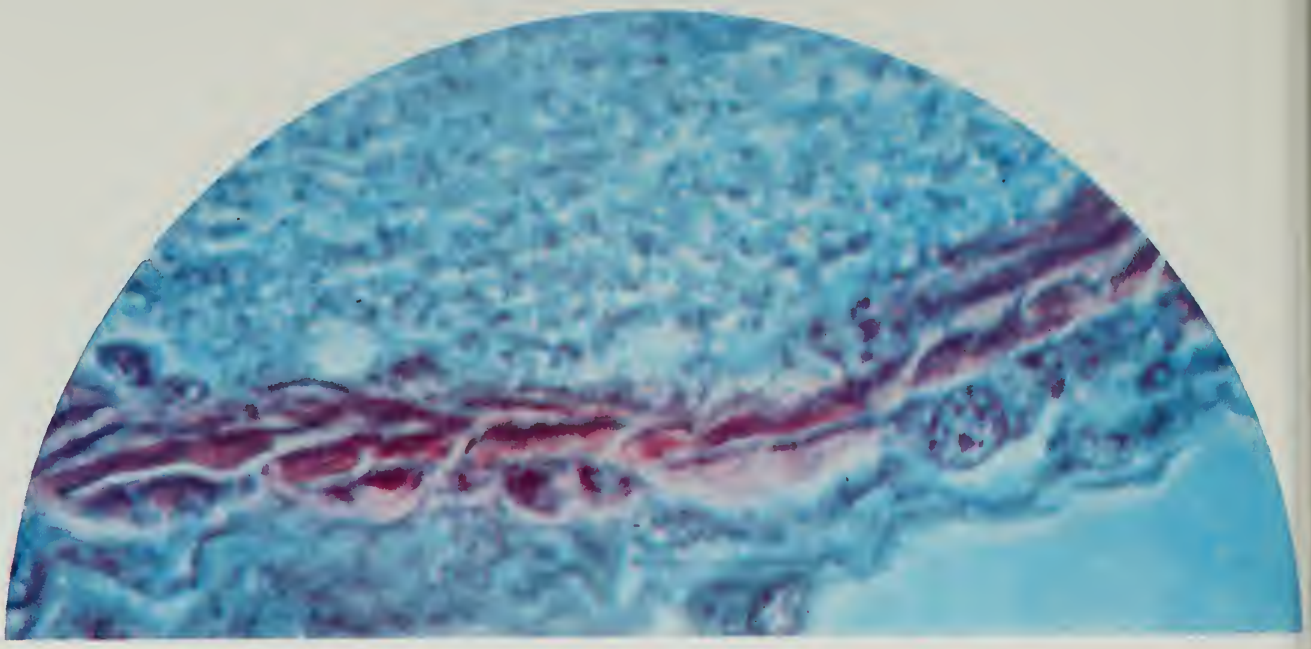


AN ADVANCED SUPPORT SYSTEM
The internal skeleton reaches its highest level of development in the mammals. As shown above in the skeleton of a cat, mammals possess four strong legs directly under the body, making walking and running easy; a rib cage protects vital organs; and a firm but segmented spine helps to give the body suppleness and strength.

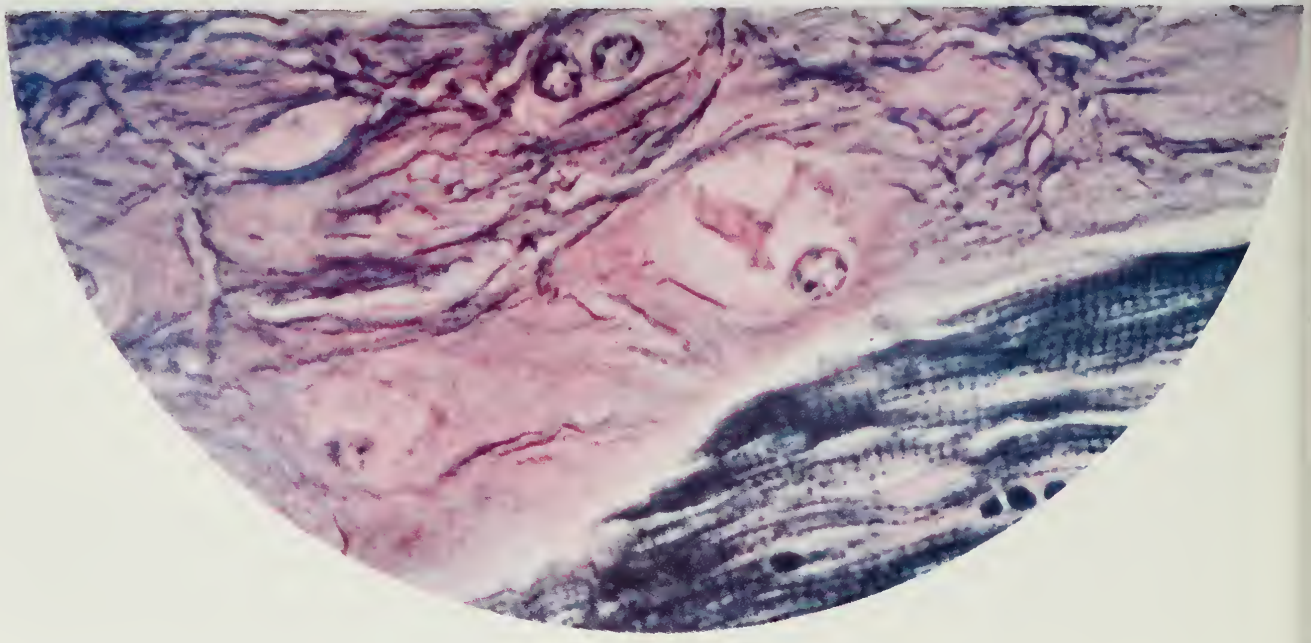
Moving Blood through the Body

In the 17th Century, the English physician William Harvey solved an age-old anatomical mystery. Drawing on some remarkably acute observations and experiments, Harvey showed that the blood of humans and many other animal species circulates in one direction through a system of vessels beginning and ending in the heart.

In a fish, for example, blood passes first through a network of vessels in the gills, where it picks up oxygen. It carries the energy-giving oxygen to the cells through a second network of vessels and takes on a load of waste carbon dioxide. The blood then returns to the rudimentary heart for another go-round. In higher animals, a complex, four-chambered heart greatly improves the circulatory system: a bird's heart beats hundreds of times a minute; a man's heart can pump five quarts of blood per minute.

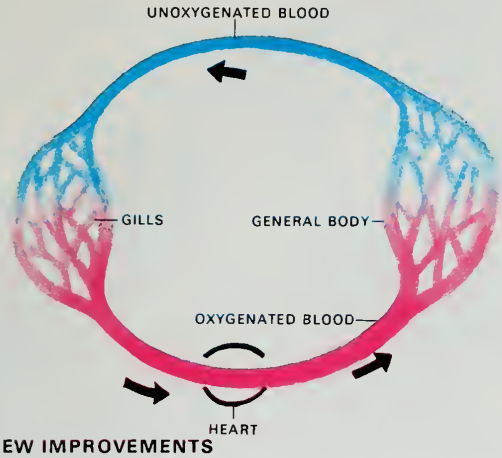


Above: Seen under a microscope, an earthworm's heart has smooth muscle fibers *(purple)* that move blood with low efficiency. Below: In a sheep's heart the muscle fibers *(blue)* are striated rather than smooth, enabling them to maintain strong, rapid beats.



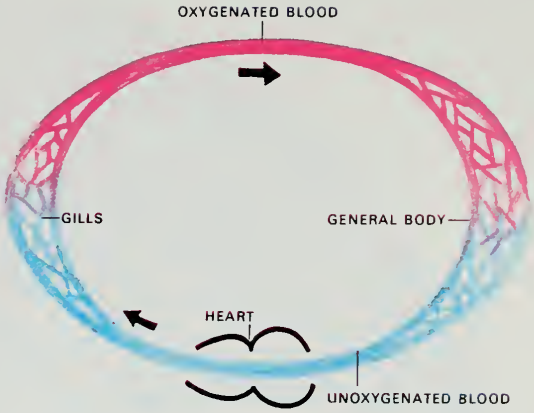
THE ELEMENTARY EARTHWORM

The earthworm *(right)* possesses the least complicated and least efficient of closed circulatory systems. Its "heart" is a group of five pairs of enlarged blood vessels, with muscular walls that constrict and relax erratically to move blood through the system. Oxygen enters the bloodstream by passing through the moist cells of the skin.



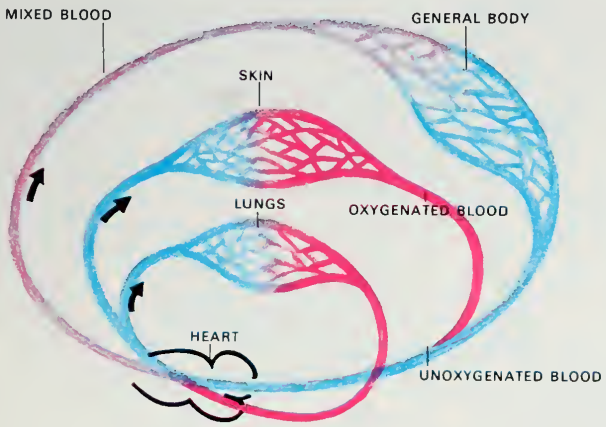
A FEW IMPROVEMENTS

A bit higher up the evolutionary ladder than the earthworm, the crayfish absorbs oxygen into its bloodstream by means of gills. The oxygenated blood *(red)* is pumped through a one-chambered heart to the general body. There it briefly leaves the closed system, bathes cells, and eventually seeps into chambers leading back to the gills.



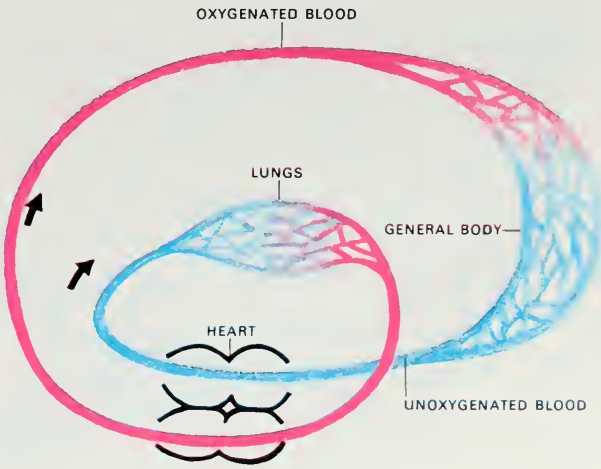
CIRCULATION IN A FISH

Like the crayfish, a bony fish picks up oxygen from the water through its gills, but the fish's blood moves within a closed system of blood vessels. Nevertheless, circulation through the fish's body is slow and inefficient, because the blood loses pressure as it passes through the intricate blood-vessel network of the gills and body.



THE FROG'S SOLUTION

The more elaborate circulatory system of a frog contains a major advance in design. The frog's blood is first pumped through two oxygen sources—the lungs and the skin—then recirculated through the heart. There the mixture of oxygenated and unoxygenated blood is given a boost in pressure and speeds out through the body.



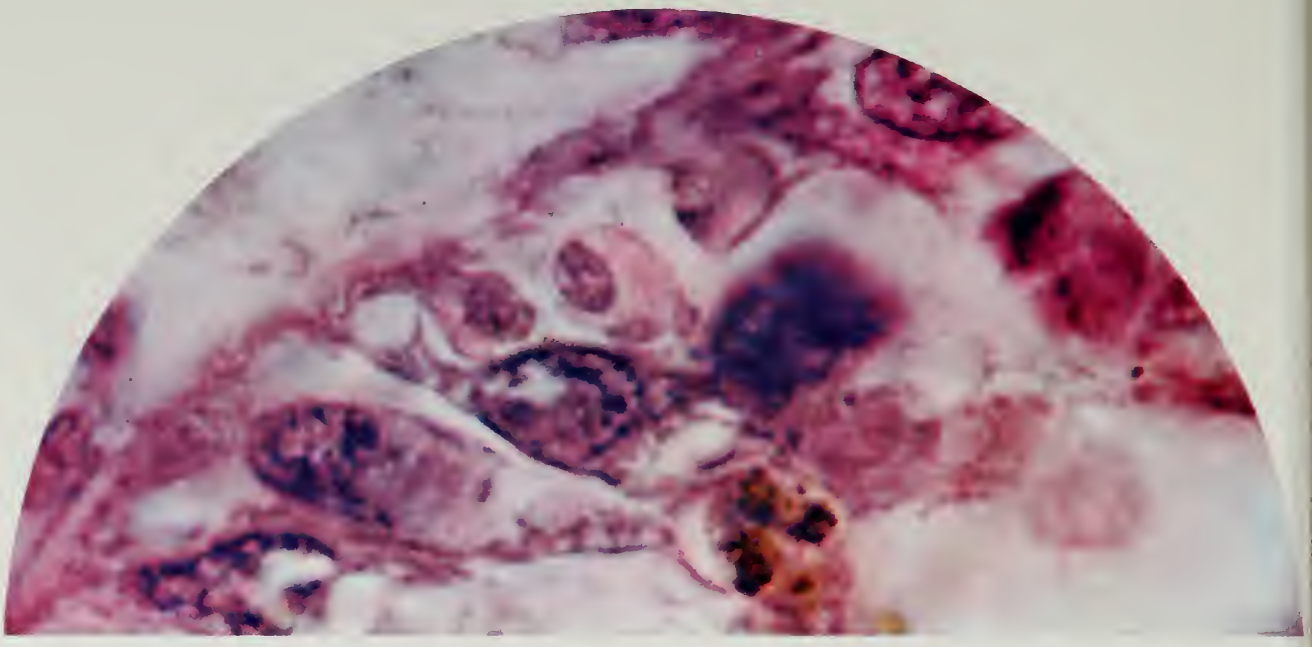
THE MOST ADVANCED SYSTEM

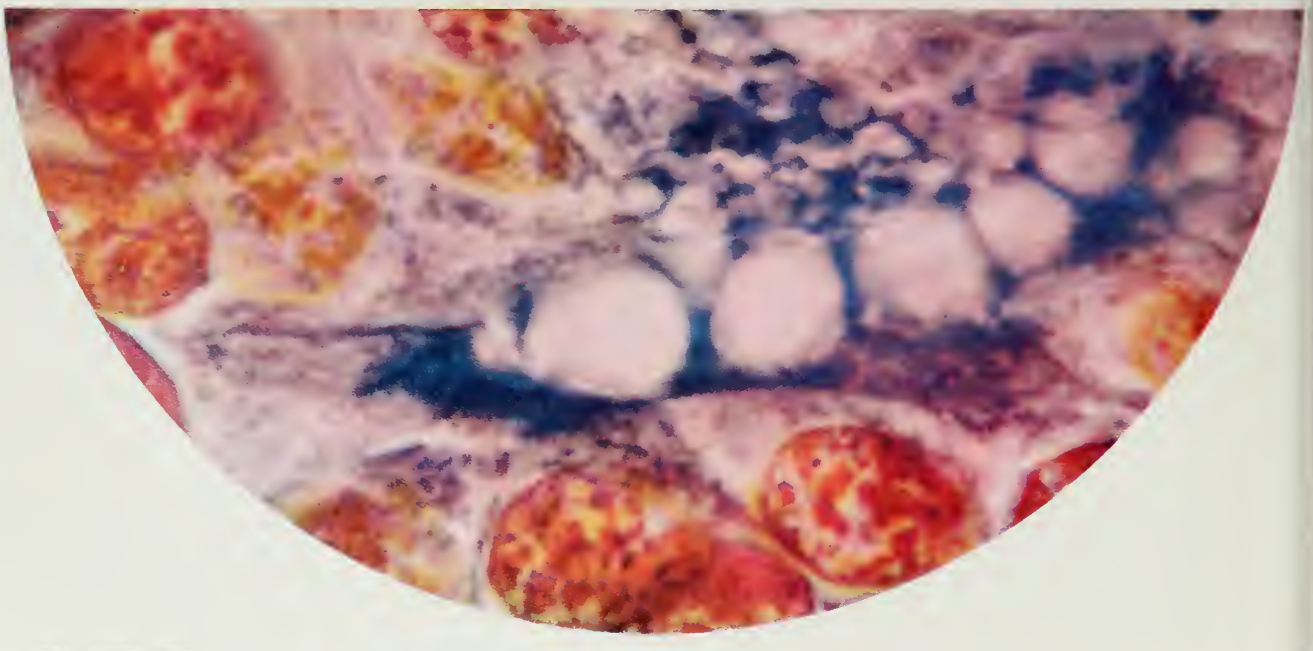
In birds and mammals, the circulatory system is immensely aided by a complex heart. One side of the heart pumps blood through the lungs to pick up oxygen; the other side receives the oxygen-rich blood and propels it out to the body. A maximum of pressure is thus maintained and the tissues are supplied constantly with oxygen.

Designs for Digestion

"I am convinced," wrote the English essayist and wit Sydney Smith, "that digestion is the great secret of life." Smith may have been speaking wryly of his own moods, but his statement is a basic truth. The explosive proliferation of animal life on this planet is based on the ability to digest an amazing range of foods, from milk by babies to wood by termites.

Very simple animals, such as the flatworm, eat particles of food small enough to be directly engulfed by cells in the body *(below, top)*. Higher animals can handle larger, more complex meals with a special digestive tract—a sort of disassembly line where food is chemically broken down and absorbed into the bloodstream. To absorb nutrients as they pass through the digestive tract, coiled and internally folded intestines of surprising length evolved; a 15-inch-long rabbit has an intestine that is 14 feet long.

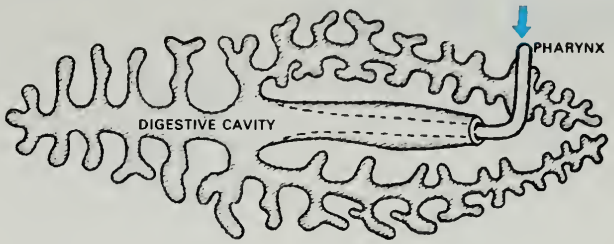


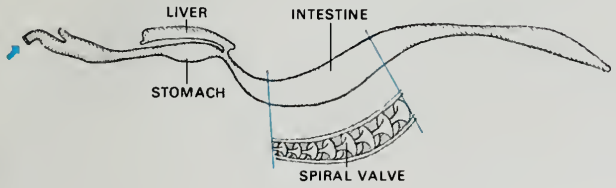


Above: A microscopic view of the digestive cavity of a flatworm shows particles of food as black dots being digested inside cells.
Below: White globules of fat inside a salamander's stomach are broken apart by enzymes *(blue)* secreted by the digestive cells.

DIGESTION IN THE TINY FLATWORM

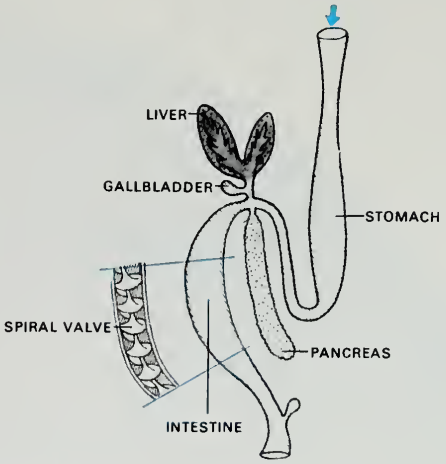
Living on plants in fresh-water ponds, the flatworm *(right)* digests minute particles of food by a rudimentary system. The food is sucked into the pharynx and enters a many-branched cavity, lined with cells that both break the food down into simpler chemicals and absorb it. Solid waste products are passed back and out through the pharynx.





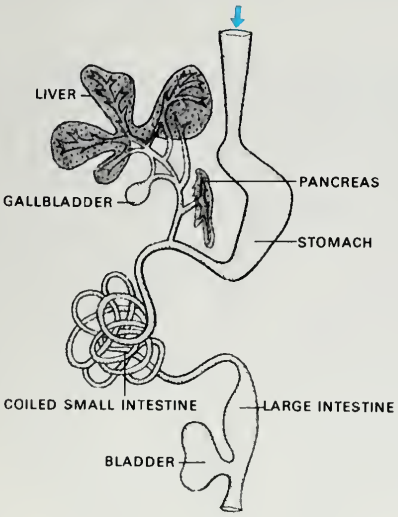
THE LAMPREY'S TECHNIQUE

The lamprey eel, feeding on the blood of other fish, has a primitive digestive tract. It contains a stomach, used mainly for storage, and a simple liver, which secretes enzymes to break down the food. The intestine is straight, but has a spiral valve *(shown here enlarged)* that multiplies the surface through which food can be absorbed.



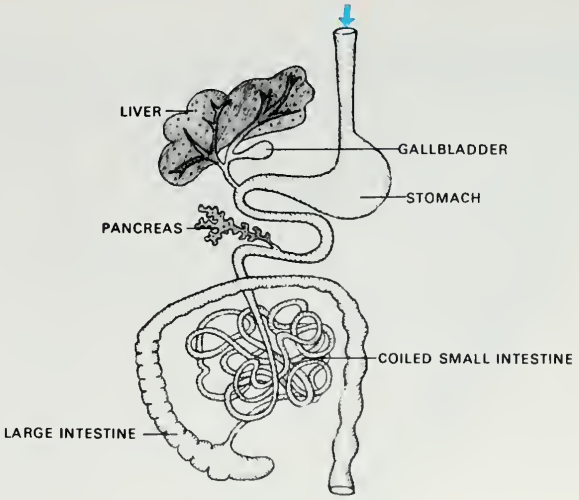
IMPROVEMENTS IN THE SHARK

The digestive system of the shark retains the crude scheme of a straight intestine with a spiral valve *(detail)*, but has a well developed stomach, liver, gallbladder and pancreas. These organs, particularly the pancreas, secrete various enzymes to break down protein, fat and carbohydrate—three fundamental nutrients contained in the food.



A MAJOR CHANGE FOR THE FROG

Instead of a spiral valve, the frog has a long, coiled small intestine, increasing the food-absorbing surface. To break down the relatively large proportion of fat in the frog's diet, the digestive system has a complex, four-lobed liver. One primitive feature is retained: the bladder still empties urine waste directly into the lower digestive tract.



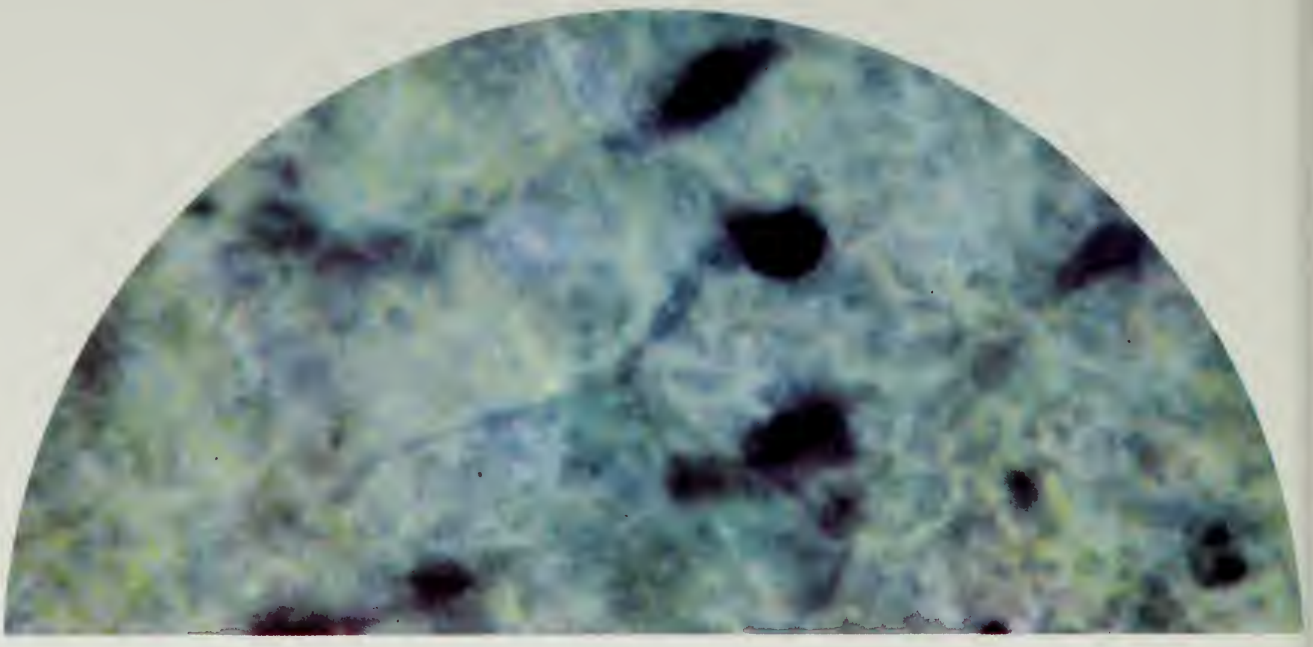
THE MAMMAL'S MODEL

Mammals have the most complex digestive systems in the animal kingdom. There is an intricately coiled small intestine—which, in a man, is about four times as long as his body. After absorption is completed, some wastes pass on to a large intestine, where they are stored before elimination. Urine waste is eliminated separately.

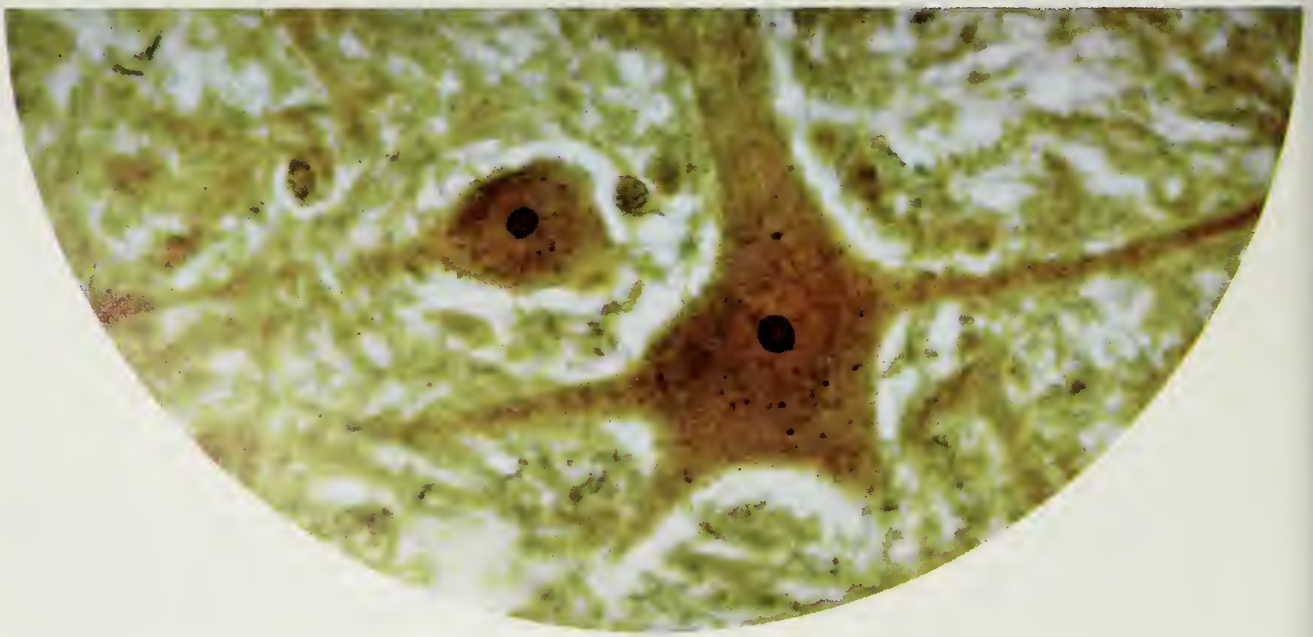
The Signal System within the Body

According to one estimate, a computer with a performance equal to the nerves in a man's eye would occupy 800 square feet of space and use four tons of electronic equipment. Yet the eye is only a tiny fraction of the human nervous system.

This superb nervous system is the end product of many ages of evolution, for nerve cells appeared at a very early stage. Even animals as primitive as the half-inch-long hydra have nerves that receive sensations from the animal's surroundings and send signals for action to muscles and glands. But the nerves of a hydra *(below, top)* resemble a telephone system without a switchboard: when one phone rings, all of them ring. Higher animals have a brain that sorts and analyzes nerve messages, thus making possible feats ranging from the swift muscle-reactions of a cat to the subtle thinking of man.

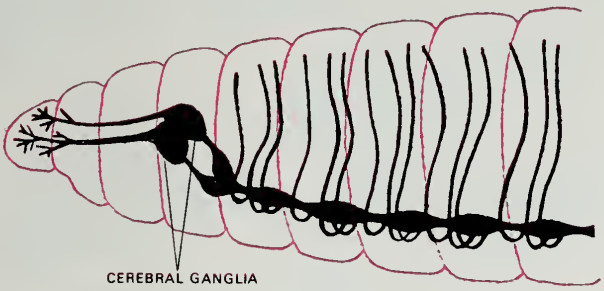


Above: In a hydra, all the nerve cells *(dark dots)* are linked together by fine fibers to form an interconnected signal system. Below: On orders from the brain, a neuron *(brown star)* in a cat's spinal cord sends commands to a single muscle via its thick fiber.



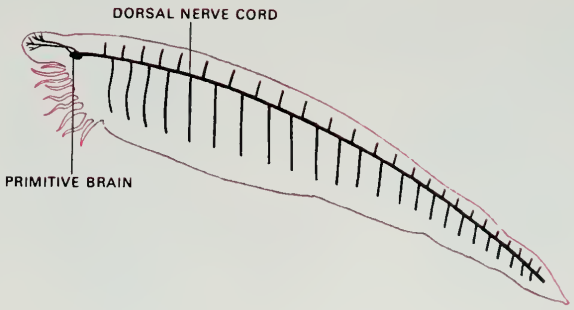
A SIMPLE NET OF NERVES

The hydra *(right)*, a tiny fresh-water animal, has a network of interconnected nerve cells. When one of the hydra's tentacles touches possible prey, the nerve signal spreads throughout the body, and other tentacles swing around to help. Simple as this system is, it enables the hydra to perform maneuvers as complex as a somersault.



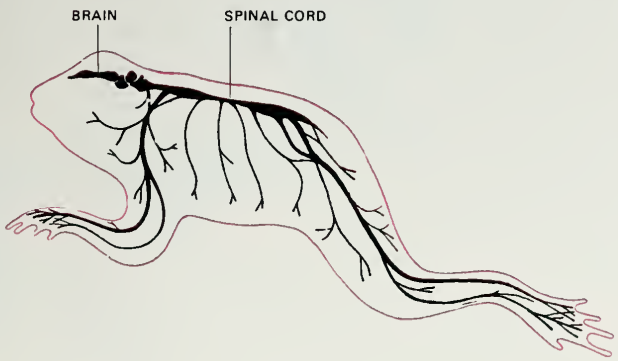
A BASIC CENTRAL SYSTEM

The earthworm has a centralized nervous system, with individual nerves in each segment of the body connected to a main nerve cord. While there is no true brain, the system contains two enlarged masses of nerve cells called cerebral ganglia *(above, left)*, which direct body movements in response to stimuli of light and touch.



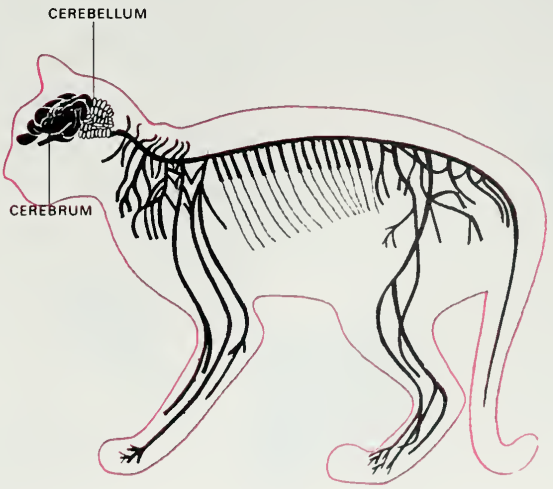
A MORE COMPLEX MODEL

A forerunner of the nervous system of higher animals is found in the tiny amphioxus. This fresh-water animal has a nerve cord running along its top side. Branching off this cord are nerves that sense light, temperature and other stimuli, as well as nerves that control muscles. At the head of the spinal nerve cord is a brainlike enlargement.



A BRAIN IN COMMAND

While the frog's nervous system resembles that of the amphioxus, the presence of a developed brain makes a vast difference. Nerve impulses to the muscles and glands are still conducted by the spinal cord, but the brain coordinates and controls these action signals with signals from the senses—sight, smell, taste, touch and hearing.



THE GREAT LEAP AHEAD

Through the development of a complex brain, mammals such as the cat gain a wide margin of superiority over the rest of the animal kingdom. Within the brain a cerebellum coordinates quick and adroit body movements, while a highly convoluted cerebrum is capable of interpretations and memory—all invaluable survival tools

Mind and Body: Clues to Healing

"A sound mind in a sound body."

The Roman poet Juvenal's classic description of man's greatest blessing has challenged science over the centuries—in large part because early recognition of the unsound is so difficult. Only in comparatively recent times has the physician possessed any diagnostic aid beyond his own senses of sight, sound or touch. And when the senses were extended by the first instruments—the stethoscope to listen to the heartbeat; the clinical thermometer to measure body temperature; the X-ray to peer inside the body—those tools were mainly useful to diagnose physical rather than mental disorders.

Not until 1911, when Hermann Rorschach, a Swiss psychiatrist, devised an ingenious test consisting of smeared inkblots, did the infant science of psychology come up with a practical means of diagnosing and defining illnesses of the mind in their early stages. Today batteries of such tests, including the one shown at right, discover hidden mental ailments. These tests, with newly devised techniques that pinpoint physical disorders, probe the mind and body for signs that often enable an attack on illness before the victim is aware of its presence.

A MIND REVEALED IN MOSAIC

In the deceptively simple Lowenfeld Mosaic Test, patterns have meaning. "Make anything you like," the patient is told as he is given a tray and 228 colored tiles. The pattern shown here stems from the unhampered imagination of a normal person. An exaggerated, discordant design might be considered by a psychologist as a suggestion of schizophrenia.

Play Tests for Mental Illness

What appear to be children's playthings on these pages are actually important tools for the clinical psychologist, whose job it is to detect and diagnose the scores of emotional disorders that constitute most mental illness. For these play tests help guide the treatment of more than four million Americans suffering from conditions ranging from nervous headaches to schizophrenia.

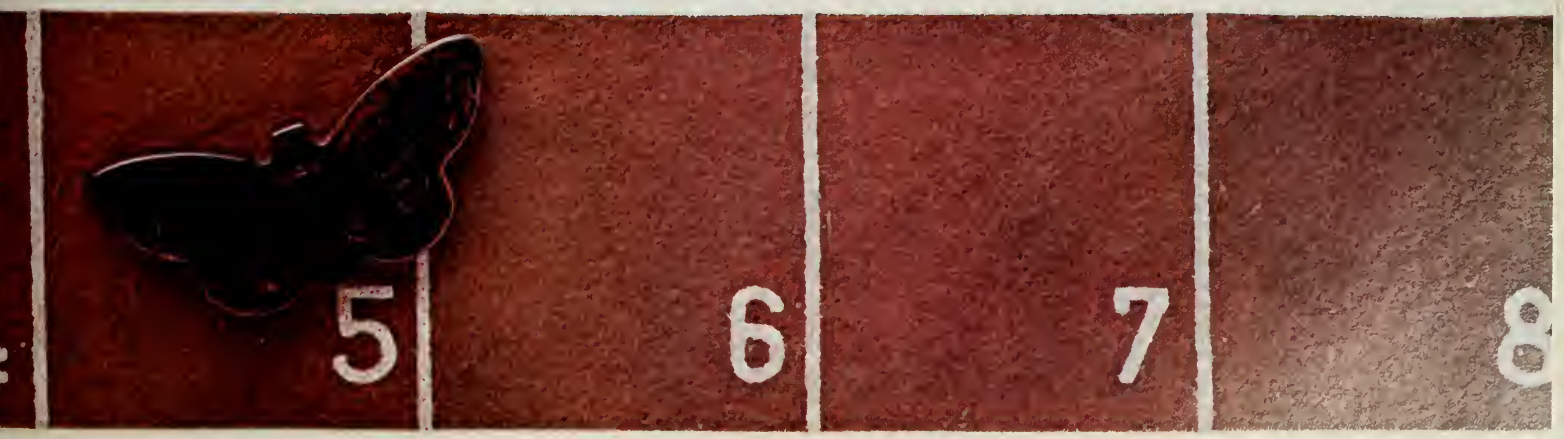
To aid in the diagnosis of mental illness, psychologists have devised batteries of tests, some of them conventional question-and-answer type but most resembling—and some even adapted from—games for children. In the examples shown here, the patient is asked simply to arrange a series of plastic figures on a numbered felt strip *(below)* or to create a picture story by placing cardboard figures against various backgrounds *(right)*. Other tests might require him to interpret ink blots, finish phrases like "If I had my way . . . ," draw a person, make up stories to match selected pictures, or even to select from groups of photographs the ones that he likes the best and the least.

The objective of each test is twofold. It encourages the individual to react in a way that reveals different facets of his unique personality, and it may uncover a behavior pattern, or syndrome, indicating a specific emotional disturbance. It is then up to the psychiatrist or psychologist to prescribe treatment that will enable the victim to deal with his problem so that he can lead a normal life.

Plastic objects often take on new meanings when placed in order of preference along a numbered felt strip in the Kahn Test of Symb

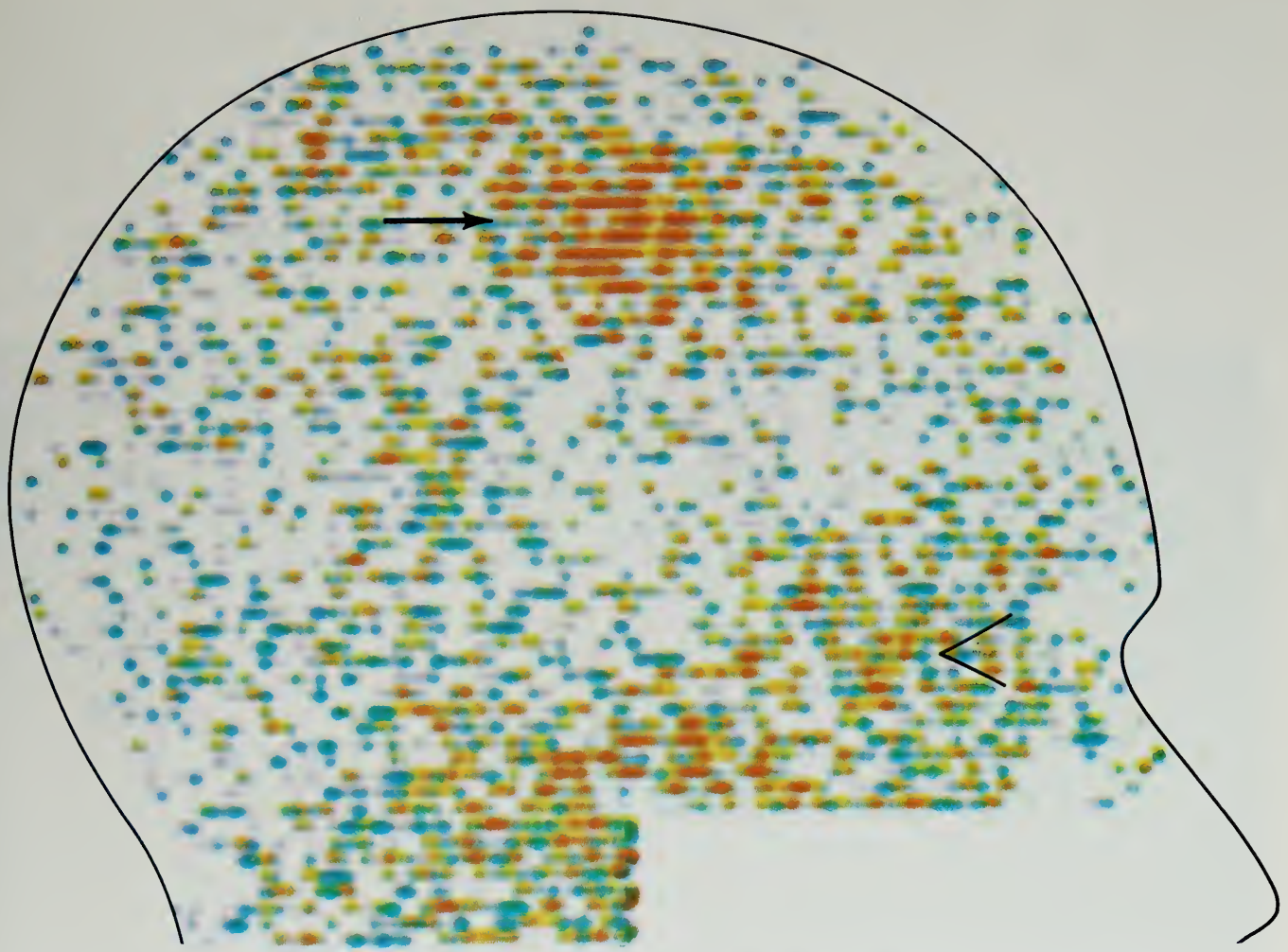
THE MAKINGS OF A STORY

The Make a Picture Story test, a versatile diagnostic tool for mental disorders, provides the patient with various backgrounds and 67 cardboard figures to use in creating a scene from his imagination. He is asked to choose figures —such as the disrobing man, distraught woman and pensive girl in the group above—and weave them into appropriate stories for the backgrounds. By observing the figures selected, where they are placed and the sort of story made up for them, an examiner can often detect sources of anxiety and emotional conflict.



Arrangement. The anchor above box 1, for example, might suggest love of adventure or fear of restraint, depending on the personality.

A rose wool skein, oddly matched with blue ones in the Gelb-Goldstein sorting test, may indicate the presence of brain damage.



Colored blips on a scanning device show a red mass *(arrow)* where a radioactive chemical, injected into the blood, permeates a tumor.

Diagnosing a Damaged Brain

So closely linked are the body and the mind that the cause of a disturbance in one often can be found in the other. Thus, worry and anxiety can produce a stomach ulcer, while a physical injury usually affects the victim's personality and behavior. About half of mental illness can be traced, at least in part, to physical causes, especially brain damage. Determining where the fault lies is obviously essential to proper treatment, but the decision is often very difficult to make. Even with subtle techniques, like those shown here, the correct diagnosis may be elusive.

A few years ago in Boston, doctors were puzzled by a young man who would break out in loud, uncontrollable laughter at inappropriate times. Eventually, telltale physical symptoms were recognized. The senses on the left side of his body had weakened, a sign of brain damage. Then X-rays and brain-wave recordings indicated a tumor was indeed pressing on the lower brain. When the tumor was removed, the laughter fits ceased.

A far more tragic case was that of a student at the University of Texas, Charles Whitman, who was troubled by severe headaches and what one psychiatrist called "overwhelming periods of hostility." Not until Whitman systematically killed 14 people—including his wife and mother—and was himself shot down by police—did an autopsy reveal a significant physical abnormality. His violent behavior may have been influenced by a brain tumor the size of a pecan.

Today psychology and medicine, working together, can often diagnose brain damage even in the absence of more obvious physical symptoms. The skeins of wool at the left are one device used in examinations that help to indicate faulty perception, muddled reasoning and poor emotional control, all signs of brain damage. In the case of brain tumors, medical techniques like "isotope scanning" *(above)*, pinpoint and define the diseased areas for the brain surgeon.

A Look inside the Body

The discovery of X-rays in 1895 revolutionized diagnostic medicine. For the first time, without opening the skin, a physician could actually see tumors, clots and broken bones inside a living body. Today the X-ray machine still ranks as one of the best and most basic of medicine's diagnostic tools, but recently developed techniques are providing newer and more illuminating views of the body's

interior. One such technique converts black-and-white X-ray prints into vivid color *(left)*, and another can detect circulatory ailments from colors produced by applying a heat-sensitive liquid to the skin.

A completely new diagnostic science called sonography is being developed with devices that use very high-pitched sound waves. So high on the scale that they are inaudible, these ultrasonic waves are beamed into the brain and their echoes are analyzed. From the echo patterns physicians have been able to locate structural changes caused by injuries and tumors lying within the body.

The advanced technology that has made ultrasonics possible has also helped convert an older instrument into a new and more valuable diagnostic tool. This is the endoscope, once little more than a thin flashlight for illuminating the large body openings. Now it has been given a greatly improved system that provides 300 times more light than the old model, but keeps nearly all heat out. Using it, the physician can watch the workings of the heart, lungs and brain—and even photograph them or televise them to consultants watching in cities hundreds of miles away.

A COLORFUL X-RAY
Arteries show up in red and veins in shades of blue-green in this color X-ray of a skull, a composite picture outlining the blood flow. It is produced by using color filters and two types of light on two X-ray plates, one made before and one after injection of an opaque solution.

A PSYCHEDELIC THERMOMETER
The color on this hand is caused by temperature variations below the skin, which has been coated with heat-sensitive crystals. The crystals glow blue over a relatively warm point and red over a cool one, revealing the local temperature changes that accompany impaired circulation.

A Trend to Automation

Almost half of the population of the United States—some 93 million people—are chronically ill, and the average healthy American gets sick briefly about twice a year.

Faced with statistics like these, harassed physicians are trying a radical new way to diagnose illnesses more swiftly and more accurately. They now use machines and computers to identify simple disorders automatically, freeing the physician for more important work.

The plastic coils at the right are part of one such machine, a multiple analyzer capable of performing a dozen different tests on a single sample of blood and recording the complete results in just 12 minutes. By linking such a machine with a computer, this new data can be interpolated into previous medical history to provide a complete health profile. The computer can even print out an updated analysis each year as the results of new tests are added.

The day may not be distant when a physician uncertain of his diagnosis can consult with the world's greatest medical authority—a computer into which has been fed the entire body of current medical knowledge—without ever leaving his office.

A MECHANICAL CHEMIST
The tints of these coils from an automated analyzer indicate how a patient's blood has reacted to some of the 12 different diagnostic tests performed by the machine. The colors are produced by blending clear blood serum with various chemical agents, and can show the presence of such conditions as diabetes and hepatitis.

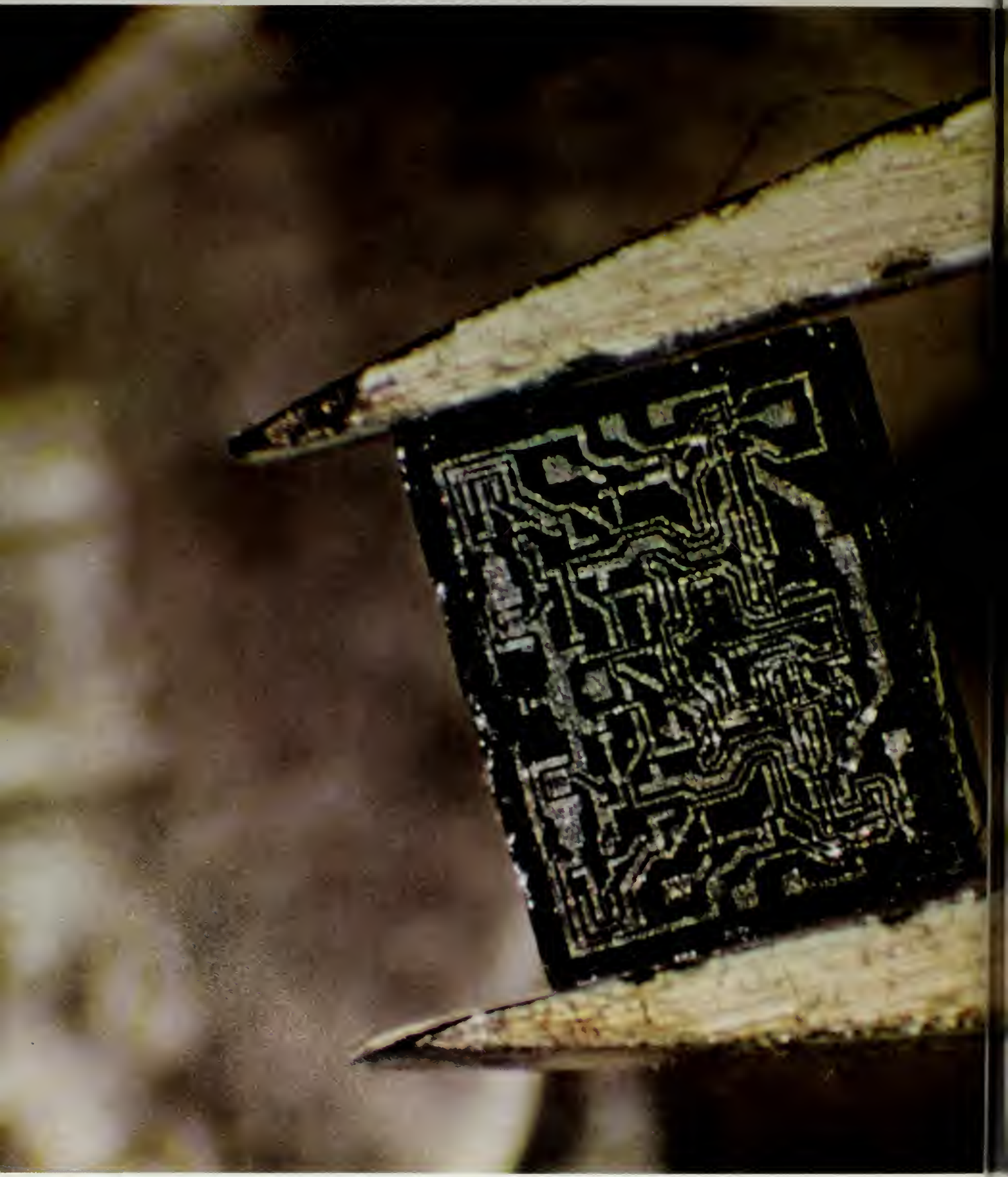
Technology: Shaper of Today's World

Our times can truly be labeled the age of technology. On every side the fruits of scientific knowledge are being applied to man's endless task of conquering and improving his environment—a term that is rapidly expanding its meaning to encompass the bottom of the ocean and the distant reaches of space. The tools of this technological revolution range from tiny microcircuits *(opposite)*, which enable computers to communicate 20,000 times faster than humans, to the power of controlled nuclear fission. By skillfully using these tools, while constantly improving older techniques, engineers have become the chief architects of modern society.

Technology began in ancient times by giving men the weapons, structures and transportation they needed simply to survive. How far modern technology has progressed can be judged by today's supersonic aircraft, interplanetary vehicles and worldwide television—all regarded as the stuff of fantasy less than a century ago. Nor is there any end in sight. Before the end of this century American homes may be equipped with tabletop computers to run appliances, cook meals, figure family budgets and help children with schoolwork by summoning data from libraries half the globe away.

A COMPUTER'S BRAIN

Miniaturized microcircuits, each smaller than a postage stamp, are soldered into computer systems like those that guide huge Saturn rockets. In 1969, when the Apollo astronauts made man's first voyage to the moon, such a computer made engine adjustments and directional changes needed to put the spacecraft on target for its 239,000-mile journey.



The Tiny, Foolproof Tools of Electronics

When the first truly modern electronic computer went into operation in 1946, its 19,000 tubes and miles of wires filled a room big enough for a tennis court. By 1958 the substitution of transistors and printed circuits for tubes and wires had shrunk a computer of similar capacity to the size of a desk. Today, using as many as 1,700 integrated circuits like the one at left—magnified 65 times—engineers can make such a computer almost as small as a typewriter.

Small size is only the obvious merit of these integrated-circuit "chips." Because each combines into one solid piece scores of electronic elements —replacing separate tubes, resistors, condensers and their soldered connections—it is far more foolproof than the old conglomeration of parts. The integrated circuit's combination of great reliability and small size makes it possible to cram sophisticated equipment, including a TV camera, radiation detectors and a device to measure magnetic fields, into the roughly four-by-nine-foot body of the Mariner spaceship that studied Mars. Now integrated circuits, applied to everyday life, can produce practical wrist radios, hearing aids implanted underneath the skin and even—if anyone wants to watch a screen the size of a quarter—a pocket-sized TV set.

A CHIP OF MANY PARTS

This magnified view shows an integrated-circuit chip held by fine tweezers. The size of a printed "o," circuits like this contain more than 100 elements, including transistors a third as thick as a human hair, and make possible new types of tiny computers, TV and radio sets

Molecules Better than Nature's Own

In 1907 Leo Baekeland produced the first truly synthetic plastic—Bakelite—and proved once and for all that men could manipulate molecules to create substances superior to anything in nature. By now about 50 basic synthetics in thousands of combinations have poured from chemical laboratories around the world. And as swiftly as materials such as nylon, Dacron, Formica, Plexiglas and butyl rubber appear on the scene, chemical engineers seek ways to adapt them to the needs of modern society. Stain-resistant fabric protectors *(below)*, fade-proof alkyd paint *(right)*, unbreakable melamine dishes, wrinkle-free polyester clothing and squeezable polyethylene bottles are just a few of their achievements.

The home of the future may be a handsome structure of molded plastic, liberated from the rectangular patterns and high costs imposed by conventional building materials and techniques. A definite possibility is a "do-it-yourself" bubble house, formed by spraying liquid plastic over an inflated form. Someday these plastic igloos may be as commonplace in America as the ranch house is today.

RESISTING AN OIL DROP
Glistening on a fabric surface, the drop of oil shown in this enlarged view is kept from soaking in by Scotchgard, a compound containing fluorine. Because such a fluorochemical resists oil and water, such finishes are used to stainproof tablecloths and upholstery fabrics.

A TOUGH COAT OF CANARY YELLOW
A brightly glowing van, freshly sprayed with alkyd paint, is "baked" under heat lamps at a truck factory. The synthetic alkyd dries to a plastic coating that is harder and far more resistant to fading than older paints, even under constant exposure to sun, rain and snow.

Improving a Basic Material

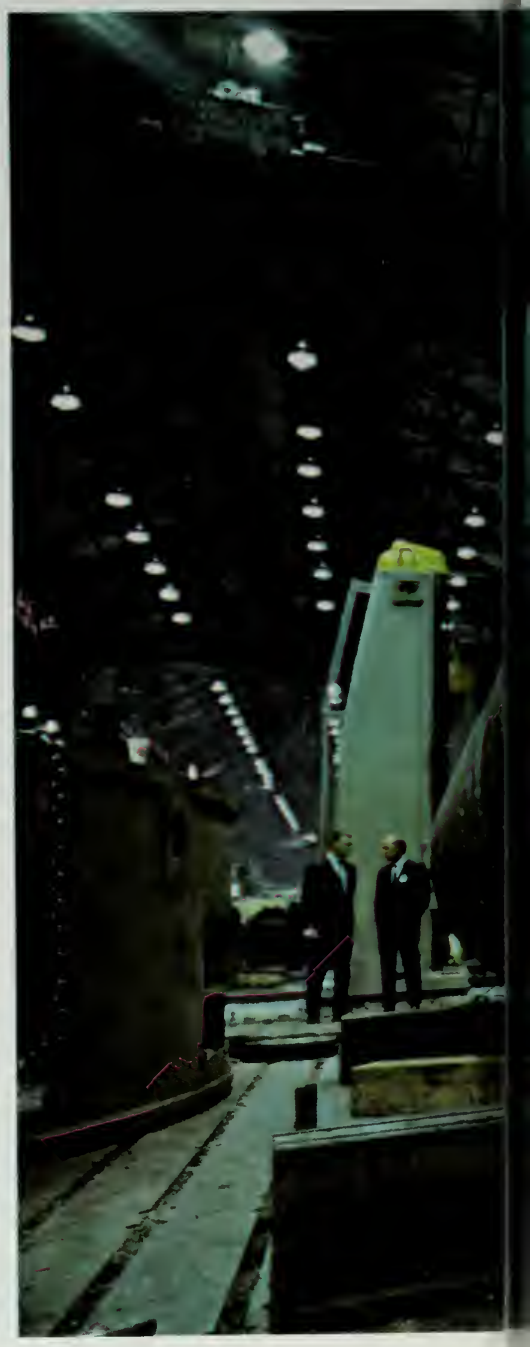
From the dawn of civilization, man's ability to shape metals into useful objects has served as a measure of his technological progress. Thus the Copper Age gave way to the Bronze Age in Europe some 5,500 years ago, and was in turn succeeded by the Iron Age around 1000 B.C. In the late 19th Century, iron had been surpassed by its by-product, steel, as the basic building material of modern technology; the glowing loop of steel pipe *(opposite)* is symbolic of the more than 500 million tons of steel produced each year.

In spite of steel's preeminence—almost enough steel is smelted in the United States each day to build five Golden Gate bridges—the metallurgical engineer constantly seeks new metals and alloys. For just as tungsten filaments proved the key to a practical light bulb, and aluminum alloy construction made the airplane a useful vehicle, so today's metallurgical research will affect the future.

Tomorrow's supersonic airliners may fly on wings of lightweight titanium, which can withstand the high temperatures (up to 500° F.) produced at 1,800-miles-per-hour air speeds. And tomorrow's electricity may travel freely through niobium alloy superconductors at temperatures close to absolute zero: –460° F.

AN ENDLESS TUBE OF STEEL

A loop of five-inch pipe snakes out of the fiery furnace mouth *(right, background)* of a pipe mill, where it has been automatically shaped and welded from flat strips of steel. At the other end of the loop, machinery stretches the pipe lengthwise, reducing its diameter to sizes for water pipe, railings and playground equipment



THE TOOLS OF ATOMIC POWER
A giant stator *(left)*, the stationary portion of an atomic-powered electrical generator, is given a smooth finish before it is fitted with a rotor like the one below, a 175-ton cylinder that will spin at 1,800 revolutions per minute. By 1980, atomic power is expected to generate almost a third of the electricity used in the United States —about 150 million kilowatts, more than enough for the needs of every American home.

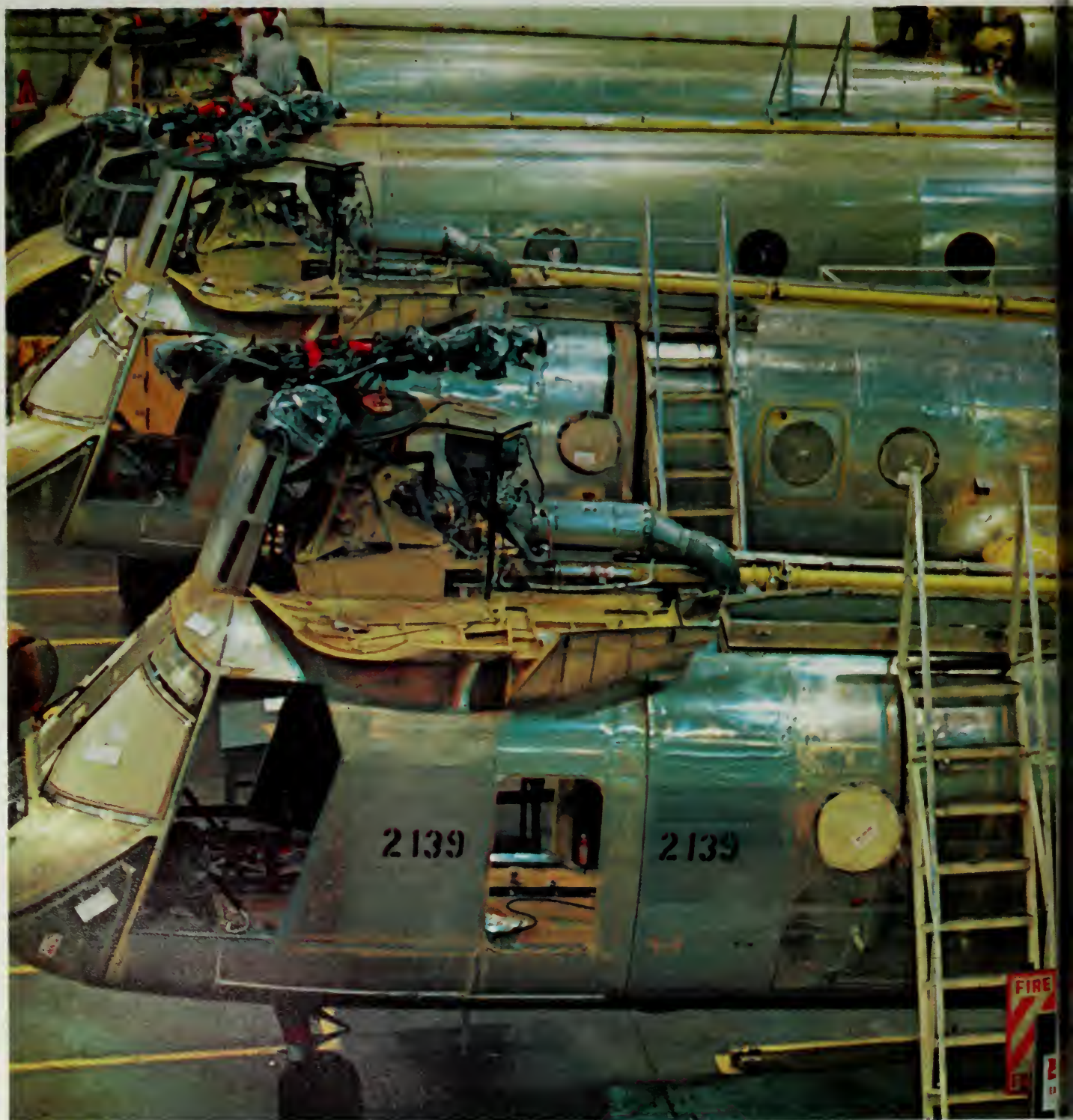
The Machinery of Power

Power is the lifeblood of an industrialized society. To the housewife, the one-tenth of a horsepower needed to whip up a cake in the kitchen mixer is as important as the 160 million horsepower (equivalent to the output of 89 Hoover Dams) required to blast a spacecraft off the ground and get it started on its journey to the moon. More than 15 billion horsepower is consumed in the United States each year.

Today most of this power comes from falling water, which spins the turbines of electrical generators, or from the "fossil fuels"—coal and oil—that generate steam in electric plants as well as drive cars and trucks. But increasingly engineers are turning to the nearly inexhaustible energy of the atom. By regulating the fission of uranium atoms in a nuclear "furnace," the engineer can operate electrical generating equipment like that shown here. Farther in the future —but offering promise of economical operation and freedom from environmental pollution—are generating plants using a form of fusion, the atomic process that powers the stars.

A New Breed of Aircraft

In 1934 aviation pioneer Igor Sikorsky predicted that speeds faster than 200 miles per hour would be unnecessary because "the size of the earth does not warrant them." Today, passenger jets cruise at 600 miles per hour; within a decade supersonic transports may hit 2,000 miles per hour; before the end of



Helicopter transports, a staple of modern warfare, move through final assembly at the Boeing-Vertol plant. The two in the foreground are

the century, hypersonic rocket planes might reach 6,600 miles per hour.

Not all of aviation technology is geared to spectacular speeds, however. The aeronautical engineer is also concerned with the advantages of vertical flight demonstrated by highly developed helicopters now on the production lines *(below)*. Work is proceeding on an aircraft that will combine the helicopter's ability with the swift flight of a conventional jet. This VTOL—Vertical TakeOff and Landing craft—could speed passengers into the heart of the city instead of leaving them at an outlying airport.

Already in production is the world's largest airplane, the Air Force's C-5, a 162-ton behemoth capable of carrying 50 tons of cargo 6,300 miles without refueling. A commercial version could revolutionize travel by flying 748 passengers from New York City to Paris for as little as $75 each.

Navy and Marine rescue and transport Sea Knights; behind them are Army Chinooks designed to carry 44 fully equipped soldiers into combat.

Grand Scale Technology

The ultimate goal of all technology is man's effective control of his environment, and nowhere is this goal better realized than in imposing bridges, tunnels, canals, highways, buildings and dams. Each represents a triumph of technology on a grand scale.

When several such structures are combined into an integrated system—like coast-to-coast railroad and highway networks, or huge urban complexes of homes, shops and schools—man makes his greatest strides toward independence from nature. The mighty dam shown here is only one unit of the Colorado River Storage Project, a system of six dams, five power plants and 2,500 miles of transmission lines. The completed project will transmit electricity to five Western states, while the six new lakes created by its dams will provide recreational areas for thousands of people; and three tunnels will divert millions of gallons of water into the Rio Grande Basin.

But although the project will produce two million kilowatts of electricity, it will be only a part of an even greater transmission system that will serve a third of North America from a power pool of 45 million kilowatts—almost as much electricity as is consumed by all of Great Britain.

NATURE RESHAPED BY CONCRETE
Flaming Gorge Dam, shown during construction, rises 502 feet above the Green River in Utah and produces enough electricity for a city the size of Spokane, Washington. Its 987,000 cubic yards of concrete, enough for a 94-mile six-lane highway, hold back a new lake 91 miles long.

Geology: Forces That Form the Earth

In *Life on the Mississippi*, Mark Twain noted that the Mississippi River was shortening itself by a little more than a mile and a third every year. If the process continued, he observed solemnly, in another 742 years the river would be only a mile and three quarters long, and Cairo, Illinois, would have become a part of Louisiana.

Although this excursion into geology contained certain flaws, Twain was in some ways closer to the truth than were the ancient Roman thinkers who called continents *terra firma*. Geologists now know that the land is never firm. Heat and the tremendous pressure contained within the earth are warping the planet's crust and pushing up mountains and plateaus. The forces of wind, water, gravity, temperature changes and chemical decay are wearing the formations down. Over a period of 100 million years or so—not very long by geologic standards—a towering mountain range can be completely leveled. Such geologic processes of construction and destruction are occurring everywhere on land and sea—and although the Mississippi has brought Cairo and New Orleans no closer today than they were in Mark Twain's time, the shape of the planet has undergone other alterations almost as drastic.

WAVES IN AN OCEAN OF SAND

The force of prevailing winds gives a crescent shape to the sand dunes of Death Valley, California. The contours of the dune begin to form when wind-blown sand encounters a rock or a plant and piles up against it. Sand blown over the top of the dune comes to rest on the downwind side, forming a steep slope. Wind rushing around the sides creates the crescent.

Building Up the Surface

The face of the earth is always being remolded. About 500 million years ago, the land on which Boise, Idaho, is built rested beneath the sea, while the site of Chicago was atop a mountain range. In the past 600 million years, the land now occupied by Manhattan has been three times lifted by mountains and reduced to sea level. Similar change is now going on in the Aleutian Islands, where, amid swirling summer fogs and winter storms, volcanoes have built and destroyed islands several times within the past century.

Most mountains are built by distortions of the earth's crust, which varies in thickness from 10 to 40 miles. Under heat and great pressure the crust can move like very stiff putty, folding the surface upward *(above)*. Occasionally, crustal rock fractures

FOLDING AND ERUPTION
The results of two distinct mountain-building processes are shown above. Sheep Mountain *(left)* rose out of a plain in Wyoming as internal forces slowly compressed and folded the earth's crust. Ship Rock *(above)*, towering 1,500 feet above the desert floor in New Mexico, is hardened lava that filled the interior of an ancient volcano. The soft ash and cinders of the volcano's cone have eroded, leaving the more resistant lava plug behind.

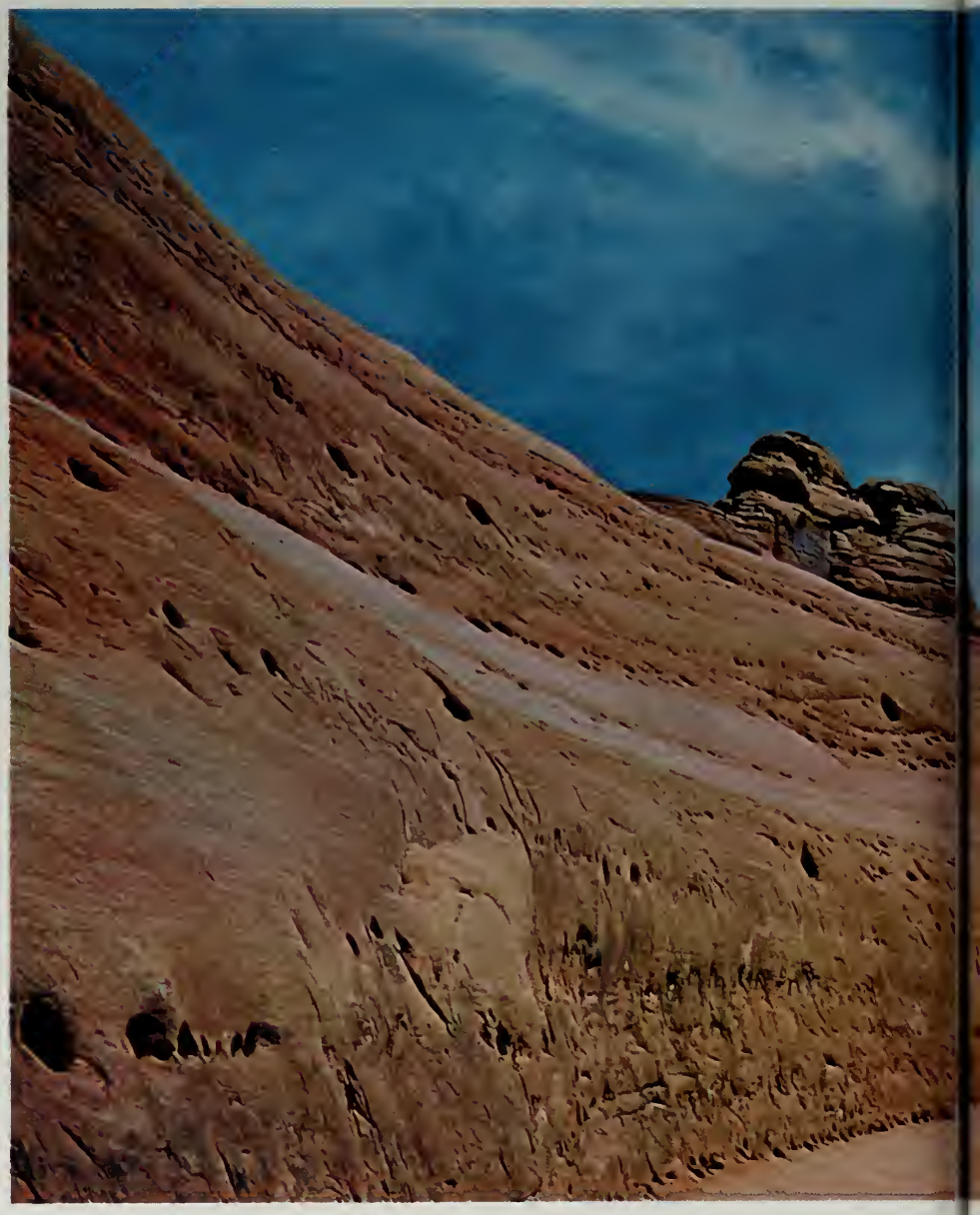
along lines of weakness called faults; the tilting of these fractures, together with the folding, creates mountains.

Sometimes solid rock in the earth's crust is heated enough to become liquid. The molten rock may pour out on the surface through volcanoes or through long fissures. Much of Washington, Oregon and northern California is built on lava that emerged from such fissures in the earth's crust.

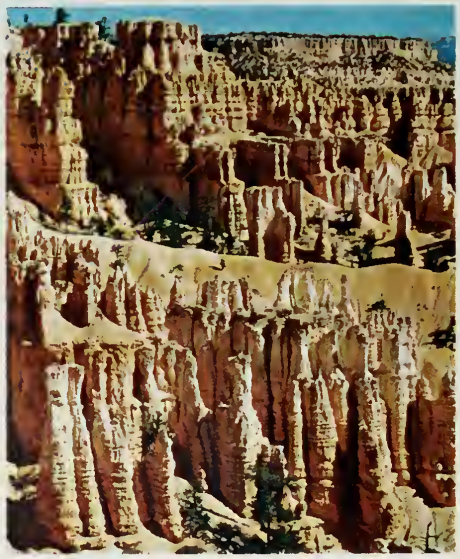
A Piecemeal Demolition

Even as rock is pushed upward, it is subjected to forces that grind it down—at rates that vary greatly. The granite Black Hills of South Dakota erode about an inch in 100,000 years (Gutzon Borglum, sculptor of the famous Presidential heads on Mount Rushmore, said that he made George Washington's nose an extra foot long to give him an added million years of durability). By contrast, the shale and sandstone that once covered the granite of the Black Hills eroded quite quickly.

Rock demolition begins with tensions that produce cracks. A host of natural forces *(below)* hammer away at these crevices in a process called weathering. Eventually the land is reduced to rubble—but its fragments will someday be compressed into new rocks to start the cycle again.



Overhanging smoothly contoured sandstone in Utah, an arch remains where rock has been worn



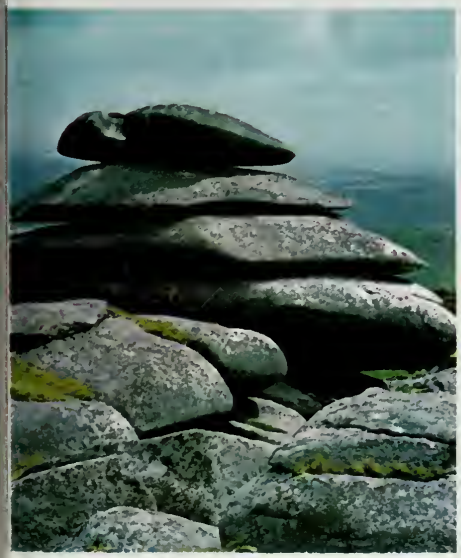
1. RAINWATER

2 ACIDS FROM LICHENS

THE VERSATILE DESTROYERS

The slow tearing down of rocks by the forces that geologists call weathering is shown in the series of pictures at right: (1) Rainwater trickling down vertical cracks cut cliffs and columns from the limestone of Bryce Canyon, Utah. (2) Acids manufactured by red lichen plants chemically decompose and pock the surface of volcanic rock. (3) A striking horizontal erosion of a few granite rocks follows the horizontal cracks that formed when the rock expanded. (4) Water, which seeped into cracks, froze and expanded, cut these jagged facets of a cliff in the Sierra Nevada. (5) Wind-driven sand sculpted the smooth curves of a formation in the Sahara.

away unevenly. Wind, frost and rain have worked through the thinner parts of the sandstone, leaving thicker parts behind to span the gap.



3 HORIZONTAL EROSION

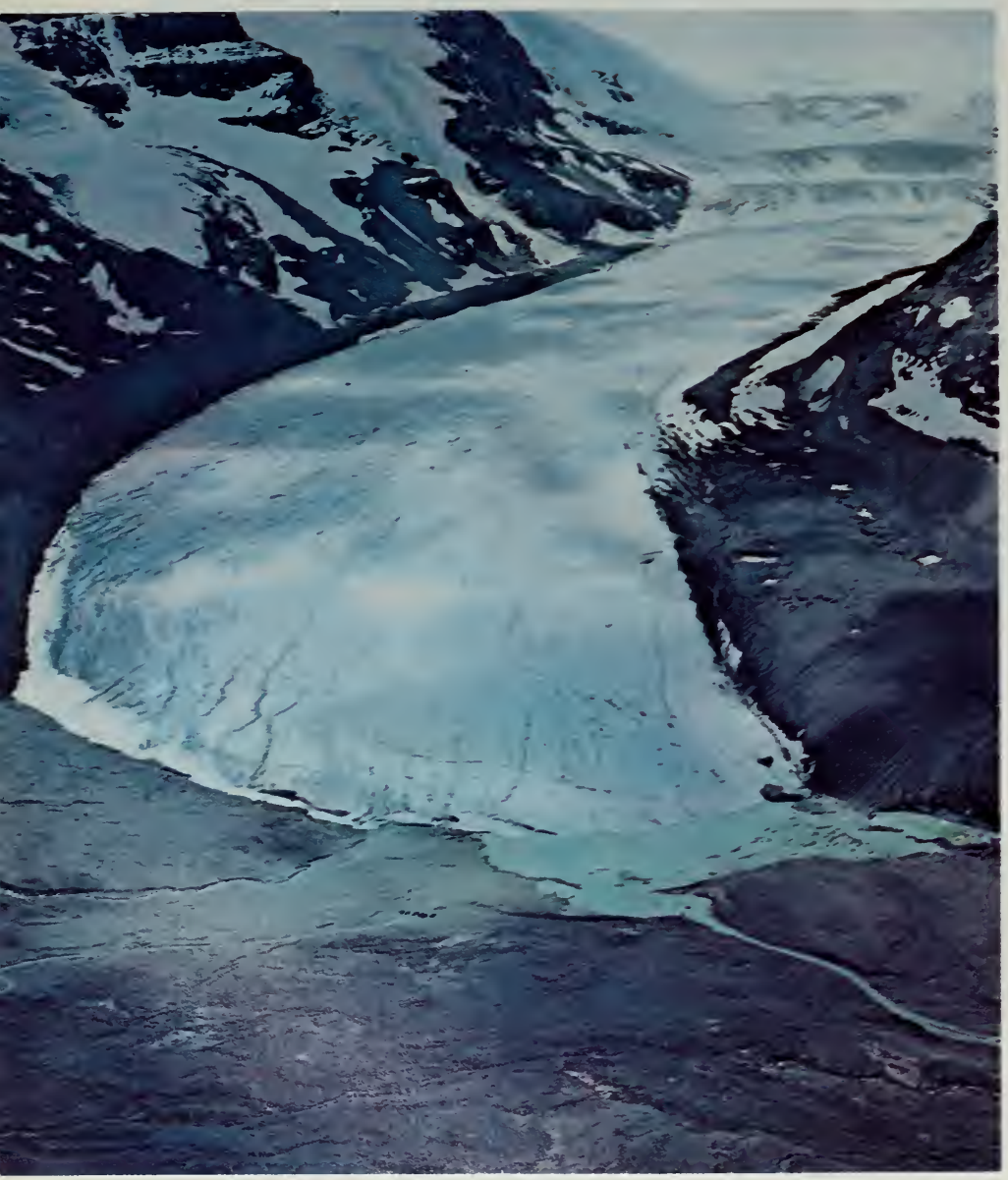
4 FROST

5 SANDBLASTING

The Cutting Power of Water

Moving water—liquid or frozen—does most of the large-scale sculpting of the earth's surface. The rivers of ice called glaciers *(below)* grind across the land at the rate of a few inches a day, gouging out mountain valleys, bulldozing away soil and dislodging huge masses of rock. These ponderously powerful glaciers form where snow can accumulate over long periods of time. As new snow piles up, the old snow beneath it is compressed into ice; under the pull of gravity, the river of ice begins to move downhill, ripping away rock and carrying debris with it. Long Island, a 118-mile-long ribbon of land east of New York City, was formed from rubble that a glacier pushed into the sea about 50,000 years ago.

Liquid water levels the land even more effectively than glaciers. Rain-



A GIANT SCULPTOR IN RETREAT
On the slopes of Mt. Athabaska in the Canadian Rockies, warming climate makes a glacier slowly recede into the valley it has gouged. The debris flanking the glacier fell as the valley walls were undermined. In front of the glacier is a layer of dirt, left behind as the ice melts.

CARVING A CANYON
Winding through southern Utah, the swift San Juan River has cut a canyon whose cliffs are 1,200 feet high. The sharp bend existed when the river was a stream wandering across a plain. When the plain was thrust upward, the river cut vertically down along the old stream course.

fall begins the work. While the impact of single raindrops on rock has no discernible effect, the damage adds up over millions of years: in a region where rainfall averages only 40 inches a year—in New York for instance—each square foot of land will be deluged by 25 million gallons in a million-year period.

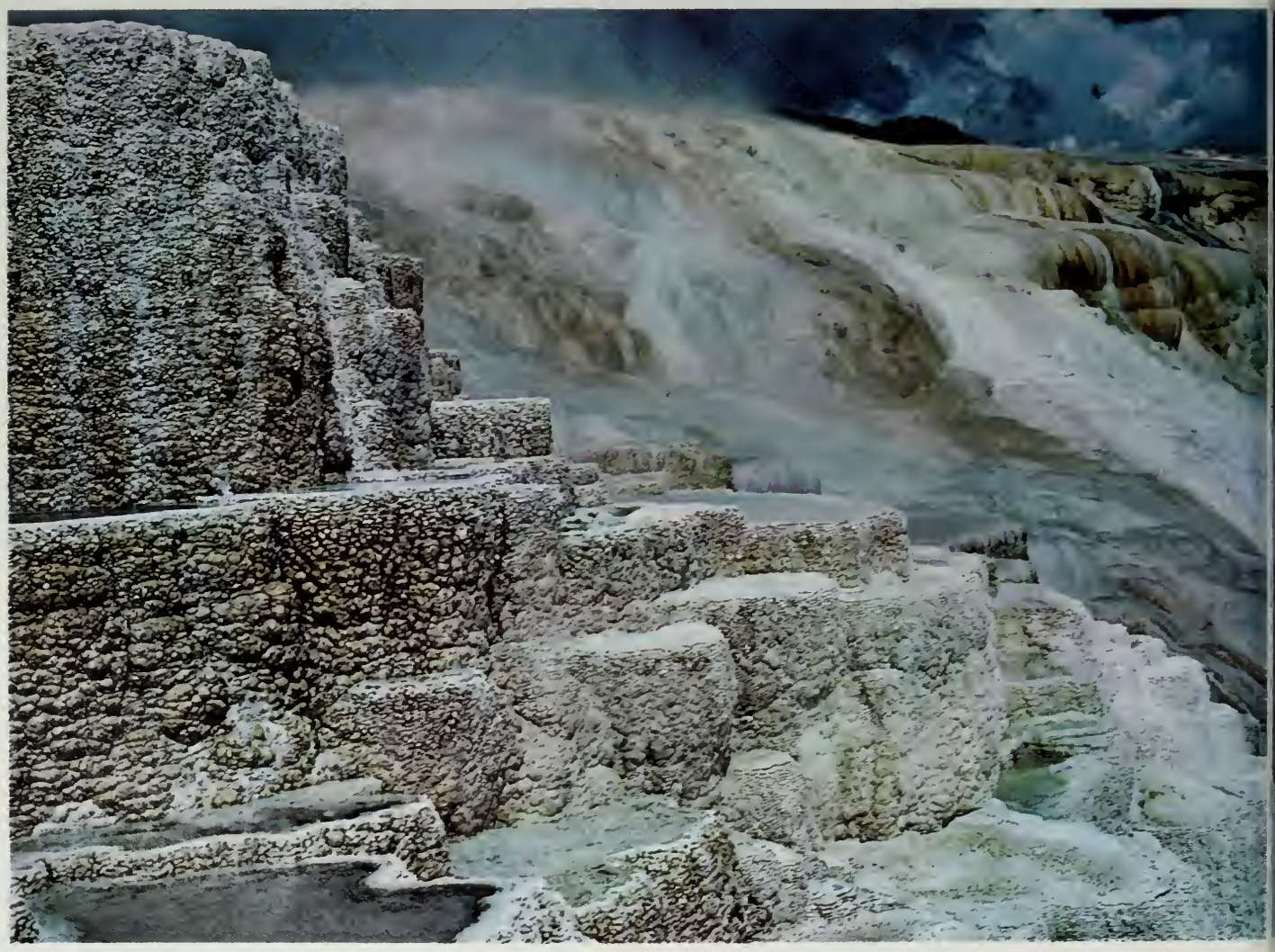
Water gathers in streams and picks up particles of rock, gaining a powerful abrasive weapon that is wielded to sculpt valleys and canyons *(below, right)*. Much of the debris from this carving process finds its way to the sea, where a new cycle of land-building may begin. The Mississippi, which drains 1,243,000 square miles of land, pours 1,400,000 tons of rock waste into the Gulf of Mexico every day, and such deposits have created a great part of the land in Louisiana.

Secret Labors of Underground Water

The Adriatic coast of Yugoslavia has the heaviest rainfall in Europe. Paradoxically, its land is as barren as a desert. The surface is completely dry because rain simply disappears, seeping down through the surface into a water-formed phantasmagoria of underworld chambers.

Such dramatic underground erosion occurs at many points on earth when the ground is underlaid with layers of limestone. The carbonic acid contained in rainwater reacts chemically with the calcium carbonate in limestone and dissolves the rock at a swift rate. In some areas, rivers flow for miles through mazes of hidden chambers, and many limestone caves are so intricate that they have never been completely explored.

Underground water produces another type of geological spectacle when it comes close to molten rock in the earth's crust, found in regions of recent volcanic activity. Heated by the rock, the water boils to the surface as a highly corrosive hot spring or a geyser. Yellowstone Park in the United States is a showplace for such displays. For decades after the discovery of the springs and geysers in the Yellowstone area, people in the East refused to believe that they existed; magazines even rejected explorers' articles about the region, regarding their accounts as tall tales.



ARCHITECTURE OF A HOT SPRING
Steaming as it pours out of a hillside in Wyoming's fantastic Yellowstone Park, a thermal spring builds characteristic terraces by deposition. Heated water is a powerful chemical solvent, and the spring picks up a rich load of mineral matter as it bubbles through rock underground. When the water cools and evaporates on the surface, the mineral residue is deposited most heavily at the edges of pools, resulting in the formation of sharply defined rims of crust.

A FAIRY PALACE UNDERGROUND

Among the most bizarre and beautiful features of the earth, the draperies in the Carlsbad Caverns of New Mexico were built by water dripping from the limestone ceiling. As the water passed through limestone, it reacted chemically with the rock to create a mineral-laden solution that falls drop by drop from the ceiling to the floor. But in the few seconds before each drop falls, some of the water evaporates, leaving behind a tiny deposit of the limestone that had been picked up earlier. These deposits accumulate to form hanging stalactites. If some of the water is evaporated on the cavern floor, stalagmites are built upwards. Such formations grow at the rate of an inch or so each century

Rising starkly out of the Pacific surf off Washington, towers of extra-resistant rock, called stacks, hold out against the sea's attack.

SANDBARS

PEBBLE BEACH

SPIT

Surging, Battering Seas

Hour after hour, day after day, century after century, waves batter the seacoasts and smash them to rubble. Sometimes shores are reshaped with sudden violence, by storm waves striking with a force of seven tons per square foot, or by an earthquake-caused wave that may be more than 100 feet high. But most changes are effected slowly. Soft rocks like shale go first, leaving behind projections of more resistant rock such as granite. But eventually these, too, will be beaten down.

Since waves hurl most of their power against the land's projections, the irregularities of a coastline are usually straightened over a long period of time. This straightening tendency is opposed by the action of currents, which pile up broken bits of rock to form spits, sandbars and beaches. These deposits slow the erosion of the waves by serving as breakwaters. Even so, the waves steadily gobble up more and more of the land—a few feet per year on Cape Cod, 17 feet per year at one point on the coast of England. But at the same time this destruction is going on, the earth's crust is rising in many places, recapturing land from the sea in the unending war between water and rock.

DEPOSITS OF ROCK WASTE

Much of the material taken from the land by waves is redeposited nearby. Spread by currents, it may form a sweeping pattern of underwater sandbars, as shown by the deposits off Cape Cod *(top)*. If the particles are too heavy *(middle)*, they will be left on the beach as pebbles to be reduced to sand. Sometimes a current carries particles past a headland, then—slowing—drops them to build a spit *(bottom)*.

The Land beneath the Sea

A century ago, many people thought the oceans were bottomless. Today, most of the ocean bottoms—comprising about 70 per cent of the planet's surface—have been mapped by echo-sounders probing the depths with sonic waves. In 1953, the Swiss physicist Auguste Piccard and his son Jacques dived to the deepest point, seven miles down in the Pacific, in a pressure-resistant bathyscaphe.

From such explorations, geologists now know that undersea terrain resembles the land surface in many respects. Across the continental shelves —submerged land that is relatively shallow—run valleys cut by rivers and glaciers when the land was exposed. In some areas, tidal currents, moving at speeds up to 12 miles per hour, continue the erosion. Swifter currents, as fast as 50 miles per hour, sometimes roll down the precipitous slopes beyond the shelves, cutting ravines and slicing telegraph cables that are in the way. These currents are probably caused by landslides on the slopes. Other currents, recently detected, draw ripples in the silt at extreme depths *(right)*.

Warring against these forces of erosion are the land-building forces that lift great mountain ranges and volcanoes from the ocean floor. Thus the same slow geological processes of lifting and leveling are going on ceaselessly even in the lightless depths.

THE WORK OF A DEEP-SEA CURRENT
A closeup photograph of ripples on the ocean floor off Cape Horn—taken with high intensity light at a depth of 13,000 feet—shows the work of a current running from the Pacific to Atlantic. The current travels at a velocity of one mile per hour—very swift for such depths.

Astronomy: A View of the Universe

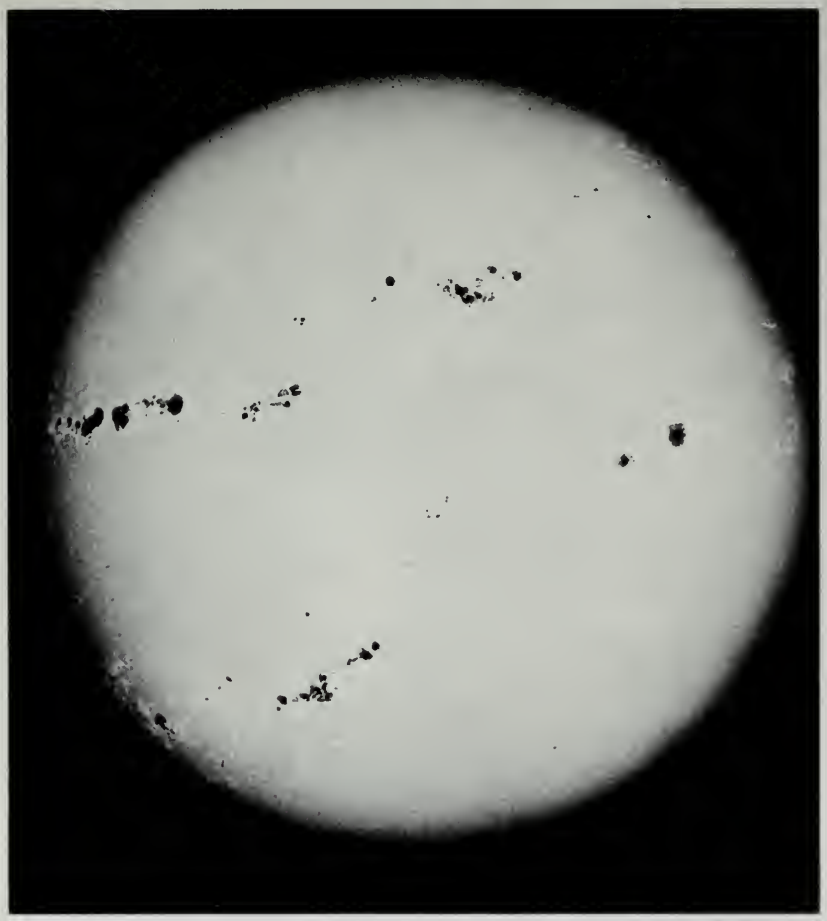
Beyond the earth stretches a universe whose size and extent dwarfs man's home planet and all his works. As modern astronomers probe deeper and deeper into space, the vastness of that universe is gradually being revealed. The sun, the largest object in the sky, is now known to be only one star among the hundreds of billions that make up our galaxy, the Milky Way. The Milky Way in turn has been revealed as one galaxy among the billions in the universe.

So immense are the distances in the universe that astronomers have had to coin their own length units, such as the light-year, in order to cope with the problem arising out of these enormous quantities, an awkward surplus of zeros. Each light-year—the distance traveled by light in a year—is 6,000,000,000,000 miles. Yet our own galaxy alone, with its billions of stars and glowing clouds of gas and dust *(right)*, measures 20,000 light-years through its bulging center, and 100,000 light-years from side to side.

And this is only a small part of the universe. Outside the Milky Way galaxies are strung for billions of light-years. Even farther out may lie tiny, incredibly brilliant points of light called quasars whose mystery has only begun to unfold.

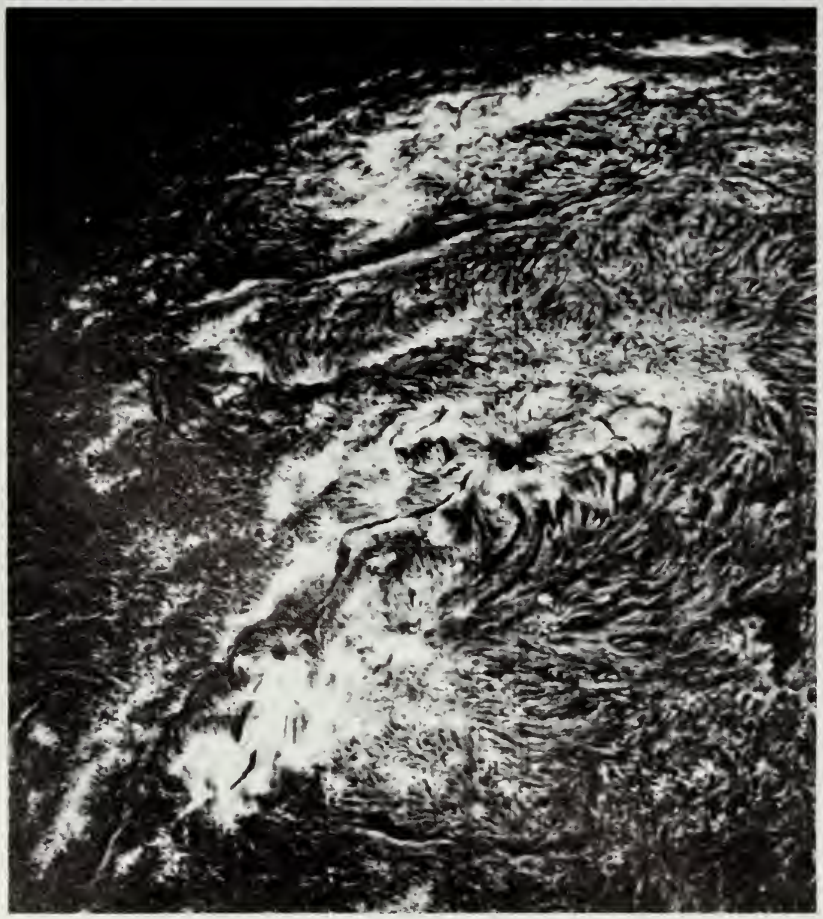
A NEBULA'S ROSY GLOW

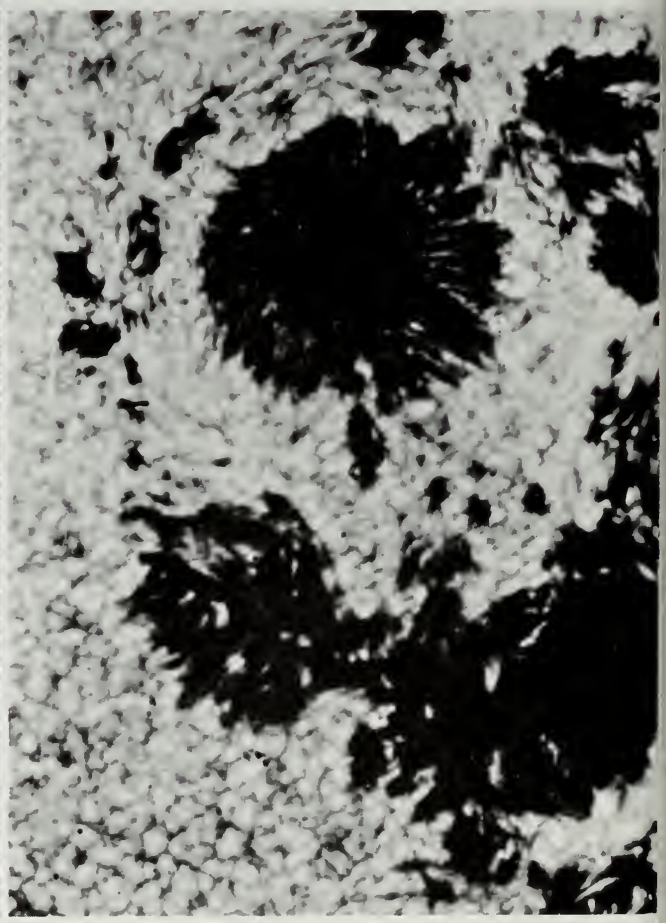
The Rosette nebula, a star-speckled cloud of luminous dust and gas in the Milky Way 5,000 light-years from the earth, glows as radiation from its stars is absorbed and re-emitted by its gas atoms. Although the gas appears as dense as fog, it is spread over so large an area that it actually is more rarefied than any vacuum created in a laboratory.

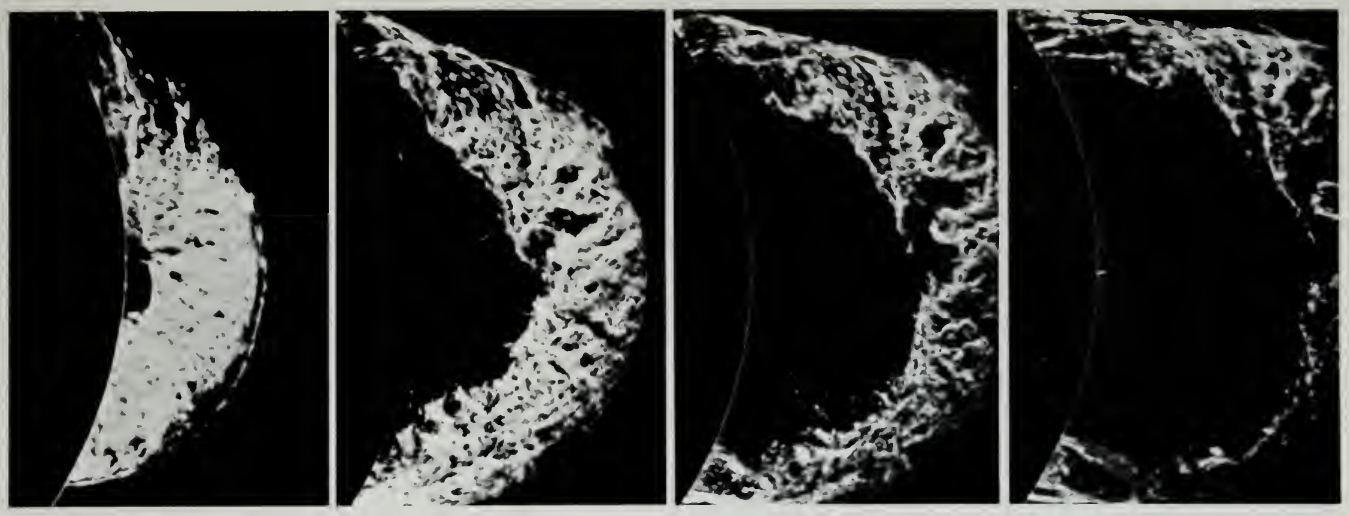


SPOTS ON THE SUN

The surface of the sun is heavily mottled with dark areas *(left)* at the height of an 11-year cycle in which sunspots wax and wane. The spots are caused by scattered magnetic disturbances that keep the sun's hot interior gases from flowing upward, thus allowing parts of the surface to cool and darken. A more detailed telescopic view of the sun *(below left)* shows the bright swirling patches of gas around the sunspots and the dark filaments that appear as prominences when viewed from the side. A still more detailed view *(below right)*, taken from a balloon, shows an active sunspot group 30,000 miles wide.







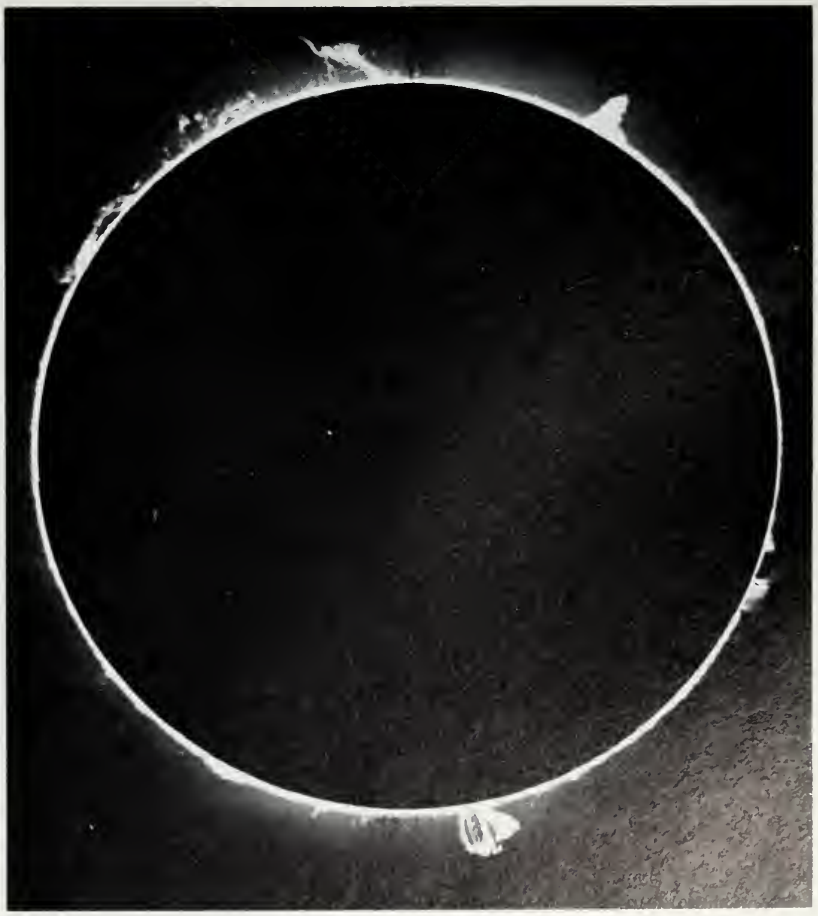
SOLAR FIREWORKS
An arch of hot gas (mostly hydrogen plus a little helium and calcium at a temperature ranging from 45,000 to 180,000° F.) boils up from the sun in a display called an eruptive prominence. The sequence above shows the largest eruptive prominence ever observed. In one hour, the gas surged outward 400,000 miles at more than 100 miles a second. Later it stretched nearly a million miles into space before disappearing.

The Most Familiar Star

Compared with the billions upon billions of other stars in the universe, the sun, 865,000 miles in diameter, is only an average star. But it is some 200,000 times closer to the earth than the next star, and it is the only star close enough to be studied in detail. Astronomical instruments have revealed the solar surface to be a seething cauldron speckled with dark spots and frothing with spectacular jets of glowing gas that spurt thousands or even millions of miles above the surface of the sun, sometimes even affecting radio transmissions on earth.

The energy for this spectacular fireworks display comes from the core of the sun. There at a temperature of 28,000,000° F. a giant nuclear furnace is at work fusing hydrogen atoms into helium. The heat from this reaction keeps the surface of the sun glowing at a temperature of 10,000° F., but local areas of the surface "cool off" sometimes, causing the appearance of the dark spots. But the cooling—to 4,500° F.—and the darkness are relative. If we could cut the dark areas out of the sun and hang them elsewhere in the sky, they would glow even brighter than the moon.

A REVEALING BLACKOUT
With the sun's face blacked out by a disk inside a telescope, the activity of the gases in its 10,000-mile-deep lower atmosphere is clearly revealed. The gas flares at the top burst from the surface and shoot straight into the sun's atmosphere. Other prominences, like those at the bottom of the picture, form arches and loops that may persist for days and then suddenly explode, flinging great bursts of hydrogen atoms into space at tremendous speeds.



A CLOUDY BREEDING GROUND

The Lagoon nebula, a cloud of interstellar hydrogen visible to the naked eye as a faint, blurred star, lies within the Milky Way 36,000 light-years from the earth. The nebula is dotted with tiny dark globules, which are believed to be dense concentrations of gas contracting to form new stars. The wide dark band lying diagonally across the bottom is a cloud of cosmic dust floating between the nebula and the earth.

A SPENDTHRIFT STAR

The planetary nebula NGC 7293 (so-called after its number in the *New General Catalogue of Nebulae and Clusters)* is a 12-trillion-mile-wide bubble of gas violently thrown off from the hot blue star at its center. Narrow streaks in the center are gases streaming outward at six to 25 miles per second—a dispersal of substance so rapid that the star will die in about 100,000 years—a mere instant in astronomical time.

The Birth and Death of Stars

Astronomers believe that stars are formed out of whirling clouds of gas and dust. The clouds contract as they whirl, causing matter to concentrate at gravity centers in their midst until stars are formed. Then as the contraction continues, the stars grow so hot that they begin to shine; at a certain point, the rising temperature can support thermonuclear reactions that convert the hydrogen of the original cloud into helium to provide the energy that the star emits as heat, light and radio waves.

A normal star like the sun will go on converting hydrogen into helium for billions of years. Then as helium ash accumulates within the star, the nuclear furnace grows hotter. The star swells, uses up almost all the hydrogen and finally cools, shrinks, turns black and dies.

Not all stars behave this way. Some erratic performers begin to rotate very rapidly after they are born. The speed of their rotation causes them to give off great clouds of gas and dust and use up their hydrogen so rapidly that they die in a relatively short time. Astronomers call these spendthrift stars planetary nebulae; the name arose through a mistake, for when the stars were first discovered, scientists believed they were witnessing the birth of planets out of nebulous clouds of gas and dust.

The supergiants—the largest stars in the sky—die even more spectacularly. When one of these monsters has used up most of its hydrogen it begins to collapse inward like an enormous tent that has suddenly had its center pole removed. Then in a final mighty fling the supergiant star throws off its remaining energy, producing a supernova, the most violent explosion in nature.

Within our own galaxy astronomers have found remarkable examples of dramatic events of the life-death cycles of stars. They can point to clouds of cosmic gas and dust where stars are probably being born. Through their telescopes they can see planetary nebulae spewing out gas and dust at prodigal rates. And they can even see the remnants of supernovae rushing outward in the sky. When they look up at the Crab nebula in the constellation Taurus, for example, they observe the aftermath of a mighty celestial explosion that occurred 900 years ago. Ancient Chinese records, brought to light half a century ago, tell us that Oriental astronomers witnessed this explosion on July 4, 1054. Cave paintings of prehistoric Pueblo Indians are also believed to have recorded the event. Today, gas from this ancient explosion is still flying outward at a speed of about 2.5 million miles an hour.

AFTER A COSMIC EXPLOSION

The gaseous nebula IC 443 in Gemini, a fragmented strand of glowing gases thrown off by an ancient supernova, stretches more than 180 trillion miles through space. This stellar explosion occurred so long ago and so far away that no star fragments can now be detected. In a few million years, every trace of the supernova will be gone. Such stellar explosions occur in our own galaxy once every 200 years, on the average.

The Worlds beyond the Milky Way

Beyond our own galaxy, billions of other galaxies dot the sky with bright, whirling pinwheels and sparkling clusters of spinning stars. Only a few of these spectacular formations can be seen from the earth with the naked eye: Andromeda, one of this small number, was early noted by Arabian astronomers and listed in a star catalogue of 964 A.D. But not until 1924 could astronomers prove that the galaxies were located outside the Milky Way. Now millions of these great star systems have been mapped and photographed in their gaudy hues and shapes.

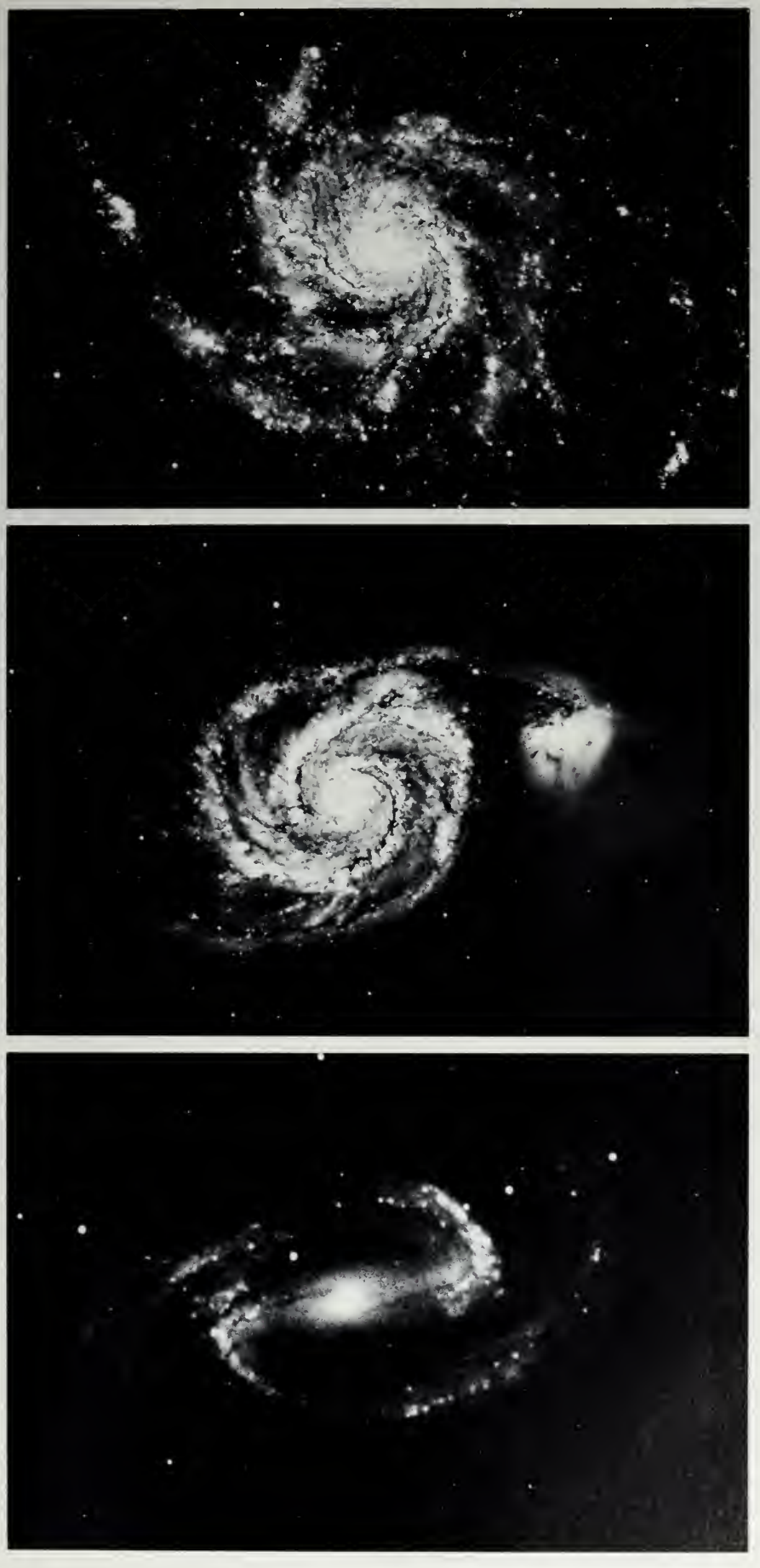
Each of these compact island universes contains perhaps 100 billion stars and each rotates at great speeds, imperceptible because of the huge distances involved.

Most galaxies fall into two major types. About 17 per cent are called ellipticals, although they range from spherical to oval in shape. In structure ellipticals are relatively simple, consisting of a tight nucleus surrounded by a halo of stars. Such formations usually are old, dust-free galaxies, glowing with the orange-red light of aging stars.

The more dazzling and more complex galaxies are called spirals. Each spiral includes a nucleus with an encircling halo of stars, and an outer disk with spiral arms flaring out from it. Such formations are relatively young galaxies, often filled with clouds of gas and dust that may be contracting to form new stars. Altogether they make up about 80 per cent of the known galaxies in the universe, including the Milky Way.

A GALLERY OF GALAXIES

Illustrated here are the two main categories of galaxies, elliptical and spiral, classifications introduced by the late Edwin P. Hubble of Mt. Wilson and Palomar Observatories. The elliptical galaxy at the top is known as NGC 147. The Sombrero galaxy *(center)* and galaxy NGC 2841 *(bottom)* are spiral galaxies. Seen edge on Sombrero has a thick encircling ring, made up of dust, gas and stars, that looks like a hat brim and gives the galaxy its name. Galaxy NGC 2841 is a looser spiral with a smaller nucleus, broken arm segments and heavy dust clouds.



A SHOWCASE OF SPIRALS
Two loose spiral galaxies, NGC 5457 *(top)* and the Whirlpool *(center),* show the most highly developed spiral forms. It is these arms that usually give these galaxies their spiral shape; but in NGC 5457 even the center shows a slight spiral pattern. The Whirlpool's arms swing around its center, and one long arm stretches out to a smaller companion galaxy nearly 14,000 light-years away. The galaxy at bottom, NGC 1300, is a barred spiral. It is distinguished by two bars running out from its nucleus with forearms, set at nearly a right angle, extending from the bars.

Odd Shapes among the Galaxies

Along with the more common spirals and ellipticals, the world of galaxies includes many nonconformists. Astronomers call them peculiar galaxies. Although no one knows exactly how they were formed, their odd shapes suggest that they were ripped apart by cosmic explosions. However, some of the peculiar galaxies may be embryonic systems evolving into normal spiral and elliptical forms. Others may be galaxies colliding.

Two features of the peculiar galaxies are of special interest to astronomers. First, their abnormal shapes aid the study of normal galaxies. Astronomer Halton C. Arp, who has catalogued nearly 400 peculiar galaxies, points out that if he could examine a normal galaxy in the laboratory,

A STAR SYSTEM BLOWING UP
An exploding galaxy, M-82 in Ursa Major, flings gas out in all directions as it is torn apart by unknown forces. In the center of the galaxy gas is hurled outward at 1,600 miles per second.

he would probe and twist it to find out how it behaves. Since galaxies are too distant and massive for this sort of experiment, the only alternative is to look at the peculiar galaxies to see what twists and deformities in their structures are possible.

A second intriguing feature of peculiar galaxies is their richness as sources of radio waves. Just as light waves reveal the shape of galaxies, radio waves tell something of their internal turbulence and fluctuating magnetic fields. And since radio observations are very little affected by clouds or daylight, radio astronomers can study these galaxies 24 hours a day. Eventually they hope to create a more complete picture of the structure and composition of all galaxies.

NONCONFORMISTS IN THE COSMOS
A group of peculiar galaxies *(below and opposite)* register a variety of strange shapes in photographs taken by wide-ranging telescopes. But how these forms are created is still not known.

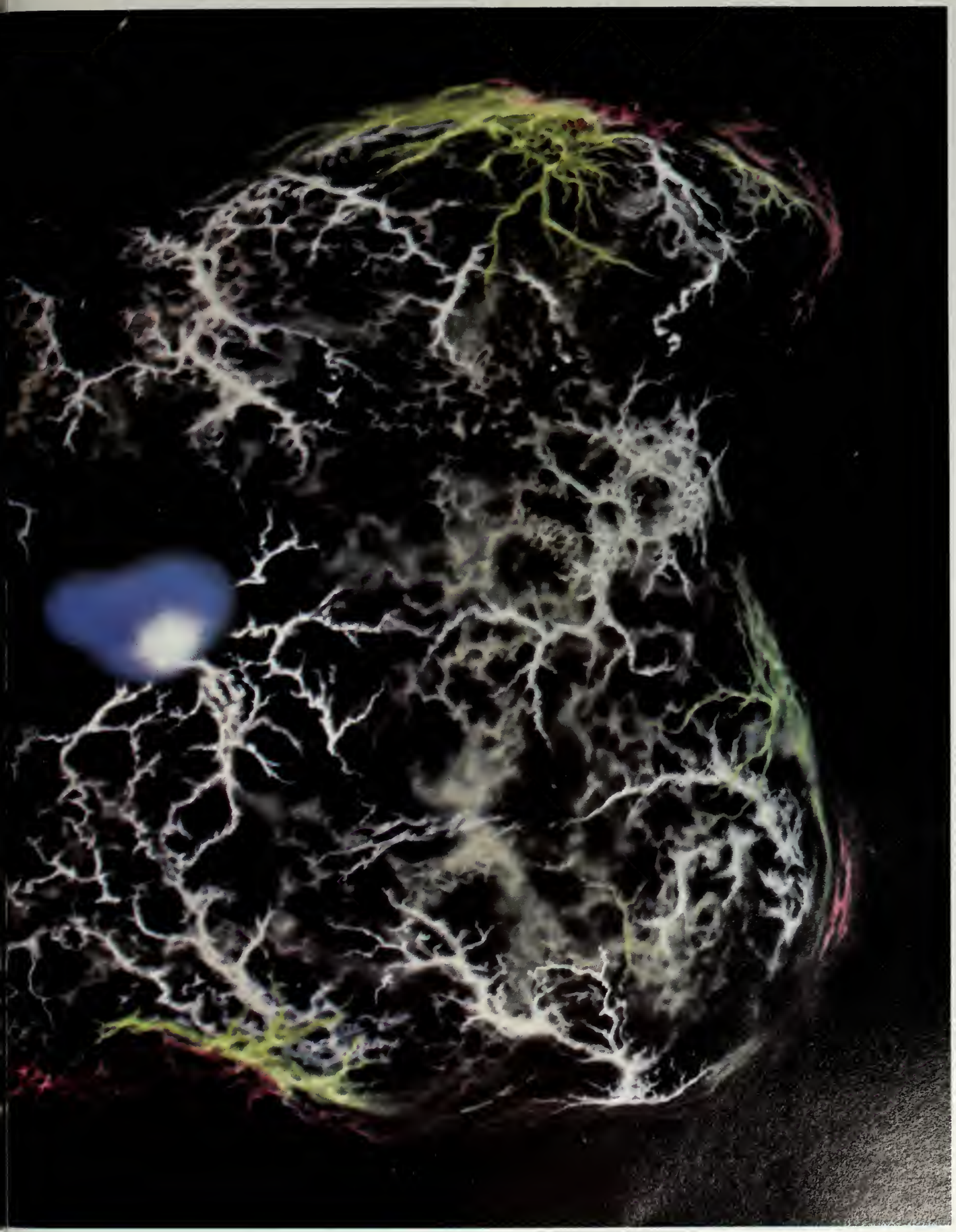
Ultimate Objects of the Universe

In 1960 radio astronomers at the California Institute of Technology and Cambridge University in England began picking up signals from a strange new source in the sky. When optical astronomers at Caltech correlated the location of the radio source with their photographs of that area of the heavens, they saw a tiny point of light that they then took to be a faint star with a rather puzzling spectral pattern of light emission.

Not until three years later, after the discovery of several more "quasars"—short for quasi-stellar sources—did the full dimensions of their mystery burst upon the world of science. Analysis of the quasars' spectra indicated that they may be the most remote objects ever detected, eight to 10 billion light-years from the earth and rushing outward at speeds as high as 150,000 miles per second. If they are so far away, these "faint" objects must actually be incredibly brilliant, each emitting 100 times more energy than is given off by all the stars in our own galaxy. No process observed in other stars can generate so much energy. Many astronomers now believe that the "fire" that keeps a quasar blazing is a succession of supernovae, as depicted in the artist's conception at right.

If quasars are indeed so distant and energetic, they may be pieces of the original universe—perhaps small, bright galaxies in the process of formation. Some of them seem so remote that their light must take 10 billion years—about as long as the universe is believed to have existed—to reach the earth. If this is so, quasars may hold clues to one of man's basic questions: how the universe was formed.

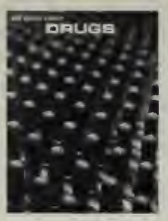
PORTRAIT OF A QUASAR
An artist's rendition of the visible part of a quasar shows a blue nucleus illuminated by supernovae in its core. The white streaks running outward from the center mark regions stimulated by radiation from the nucleus. As the brightness fades on the outer edges of the quasar the color turns to green and then red.



Using the LIFE Science Library for Schoolwork

The LIFE Science Library provides a rich supplement to school courses with easy-to-understand explanations of difficult subjects, historical background, lively discussions of people and places, and many pictures of science at work. The chart on these foldout pages organizes the library especially for students (and for teachers and question-harried parents).

Listed vertically on the left-hand side of the chart are 82 topics. Selected by a group of education experts, they represent the core of the school science curriculum. To use the chart, the student first locates a topic in the vertical list. By moving horizontally across the chart, he finds references to discussions of the topic in various volumes, which are listed along the top of the chart. For example, if he traces the topic of WATER across the chart, he will discover that it is studied from many different points of view. Not only is one whole book devoted to the subject but also 15 chapters and 12 picture essays of other volumes. The *Planets* volume discusses water elsewhere in the solar system; *Ships* treats man's development of transportation across bodies of water; and the *Water* volume deals with the topic in hundreds of ways—from the behavior of the water molecule to the role of water in geology.



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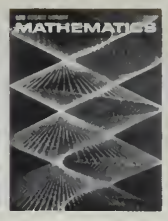

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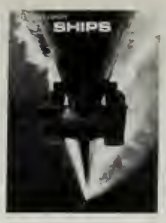

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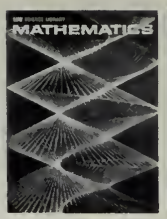

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But this index is more than an A-to-Z compendium of names and subjects. Incorporated in it are a number of master entries—each a major area of a scientific study—that simplify the finding of information about big, complex subjects. Under Rockets, for example, are listed a number of paragraphs that break down the subject of rockets into categories identified by subheads: engines of, escape velocities of, fuels, history of, materials and steering. By looking first for a master entry, checking its subheads, and then glancing over the list of references under each of the subheads, the reader will very quickly be led to special information in any book in the LIFE Science Library.

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ACKNOWLEDGMENTS

The editors of this book are indebted to the following persons and institutions: Halton C. Arp, Mt. Wilson and Palomar Observatories, Pasadena, Calif.; R. Grant Athay, High Altitude Observatory, Boulder, Colo.; Franklyn M. Branley, American Museum—Hayden Planetarium; Fred Brown, Dept. of Psychology, Mt. Sinai Hospital, N.Y.C.; Robert E. Danielson, Dept. of Astronomy, Princeton University, Princeton, N.J.; G. Gail Gardner, Instructor of Psychology, Bernard Landis, Clinical Asst. Prof., Cornell University Medical College, N.Y.C.; Harry J. Gray, Prof. of Electrical Engineering, University of Pennsylvania, Philadelphia; Jesse L. Greenstein, Alan T. Moffet, Maarten Schmidt, California Institute of Technology, Pasadena, Calif.; Thomas Haines, Prof. of Biochemistry, Ray Keywork, Dept. of Chemistry, Walter E. Miller, Prof. of Chemistry, College of the City of New York, N.Y.C.; Bruce Heezen, Lamont Geological Observatory of Columbia University, Palisades, N.Y.; Sidney Horenstein, American Museum of Natural History, N.Y.C.; Theodore C. Kahn, Dept. of Behavioral Science, Southern Colorado State College, Pueblo, Colo.; N. M. Larson, Pfizer Ltd., England; R. I. Louttit, A. Trakatellis, Associate Scientist, Brookhaven National Laboratory, Upton, N.Y.; Margaret Lowenfeld, Director of Training, Institute of Child Psychology, London; Stephen P. Marion, Prof. of Chemistry, Brooklyn College, Brooklyn; Kirtley F. Mather, Prof. of Geology, Emeritus, Harvard University, Cambridge, Mass.; John Mellecker, Technicon Instruments Corporation, Ardsley, N.Y.; Yukihiko Mitsui, Tokushima University School of Medicine, Japan; Robert T. Morrison, Vancouver General Hospital, Vancouver, B.C.; William L. Newman, U.S. Dept. of the Interior, Washington, D.C.; Richard M. Perdue, Texas Instruments, Dallas; Joseph S. Rychetnik, Anchorage, Alaska; Edwin S. Shneidman, Center for the Studies of Suicide Prevention, National Institute of Mental Health, Chevy Chase, Md.; Judith Hardy Stashin, N.Y.C.; William Stennis, Albert Einstein Medical Center, Philadelphia; 3M Company, Dept. of Communications, St. Paul, Minn.; Phyllis Weinberg, Pennsbury School System, Fallsington, Pa.; Robert E. Wise, Lahey Clinic and New England Baptist Hospital, Boston; Luise Zucker, Clinical Psychologist, N.Y.C.

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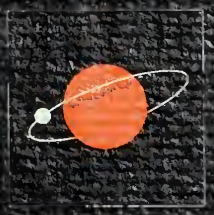
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